UP IN SMOKE: EXPLORING THE RELATIONSHIP BETWEEN FOREST FIREFIGHTING AND SUBSISTENCE HARVEST

by

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Abstract

Wildland firefighting in Alaska is changing due to the impact of climate change on the boreal forest. Changes to the wildland firefighting regime could have significant impacts on community participation during fall subsistence hunting and, consequentially, food security levels. Many rural Alaska communities have mixed cash-subsistence economies in which people have to balance their time between earning an income and harvesting subsistence foods. Cash income is necessary to pay for things such as housing, electricity, gasoline, gun, ammunition, and other capital necessary to engage in subsistence.

This dissertation aims to better understand the current relationship between Type 2, or hand crew, wildland firefighting and subsistence, primarily fall subsistence hunting, through several methods. Surveys and interviews were conducted with Type 2 wildland firefighters followed by policy recommendations. Econometric modeling of the wildfire attributes, community attributes, and firefighting wages and dispatches was conducted. Lastly, a food production simulation was conducted. Utilizing these various methods gives a well-rounded understanding of the relationship between firefighting and subsistence. Firefighting wages currently contribute to subsistence harvest productivity. As climate change lengthens the fire season, rural Type 2 fire crews will continue to participate in firefighting and fall subsistence hunting. Only under the most extreme estimates of future wildland fires does time spent fighting fire reduce time spent on subsistence fall hunting by much so that rural communities are unable to meet their subsistence needs.

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Chapter One: Introduction

1.1 Introduction

The firefighting-subsistence system involves several complex moving parts which function together to create employment opportunities that accommodate and enable subsistence lifestyles. This system has and continues to create challenges or opportunities for rural Alaska community members that engage in Type 2 firefighting, firefighting on hand crews.

Wildland firefighting management has undergone policy and regulation changes, as has the boreal wildfire regime, due to climate change. These changes cause cascading alterations that are the focus of this paper. This paper investigates how changes, primarily climate change, will ultimately impact subsistence harvest levels. Due to the complex nature of the firefighting-subsistence system, these changes cannot be considered in a vacuum. Hence, the inclusion of policy and regulations that impact this firefighting-subsistence system. Ultimately, the author hypothesizes that climate change will result in decreased fall subsistence hunting levels.

1.2 Chapter Two: Climate Change Overview

Chapter two will explain the firefighting-subsistence system, including the ecological and social aspects of the system. Both the firefighting management organization and crew rotation system will be outlined, and the pathways of cascading changes will be illustrated. The ecological connections between climate change and the boreal wildfire regime will also be made clear in this chapter.

1.3 Chapter Three: Surveys, Interviews, and Policy Evaluation

Chapter three will outline survey and interview research undertaken to understand how wildland firefighters currently balance firefighting and subsistence harvesting. The surveys and interviews go further by inquiring as to how firefighters anticipate balancing these activities if the fire season extends into the fall hunting season. This chapter will describe the survey and interview methods, walk through the results, and discuss the implications of the findings. Lastly, chapter three will evaluate policies and regulations, which were identified in prior research and interviews that create challenges for firefighters and their communities. Policy and regulation changes are suggested by the author and interviewees.

1.4 Chapter Four: Economics of Firefighting and Econometric Models

Chapter four delves deeply into the economics of the firefighting-subsistence system. Two econometric models are presented that evaluate the impact of increasing boreal acres burned. The first model evaluates the impact of various factors – including Alaskan acres burned, community geography, and Lower-48 acres burned – on firefighting wages. The second model calculates the impact of similar independent variables on the number of firefighting dispatches. Together, these models help inform the relationship between wildfire, wages, dispatches and time available for subsistence.

1.5 Chapter Five: Food Production Simulation

Chapter five uses a Becker-style conceptual household production model to layout a community food production simulation. The community food production, subsistence, and market simulation is parameterized using data from several sources including Alaska Department of Fish and Game, Alaska Department of Labor and Workforce Development, Alaska Department of Natural Resources, and the firefighter surveys and interviews discussed in Chapter three. This simulation is conducted for an average roaded – on the road system – and non-roaded – off the road system – community.

1.6 Chapter Six: Conclusion

Finally, the conclusion summarizes the findings of all prior chapters to holistically describe the expected changes to the firefighting-subsistence system. This chapter brings together econometric models, food production simulations, and firefighter surveys and interviews to envision different pathways forward. The chapter also briefly revisits how suggested policy and regulation changes could help empower local residents to adapt to a changing future in a beneficial way.

Chapter Two: Climate Change and the Boreal Wildfire Regime

Abstract

Wildland firefighting in Alaska is changing due to the impact of climate change on the boreal forest. Changes to the wildland firefighting regime could have significant impacts on community participation during fall subsistence hunting and, consequentially, food security levels. With high rates of Rural Alaska food insecurity and concerns over continued participation in subsistence food harvesting, this research on the relationship between firefighting and subsistence, and the related potential changes to the wildland firefighting system due to climate change, is both timely and vital.

This chapter demonstrates the clear link between climate change and increased boreal wildfire activity, which has created the changing conditions necessitating this research. Beyond the biological, this chapter lays out the social systems and policies at play that affect how Type 2 firefighters, hand crews, and Rural Alaskans in general are impacted by climate change and specifically a longer firefighting season.

2.1 Firefighting and Subsistence

2.1.1 The Need for Research

Wildland firefighting in Alaska is changing – for example longer seasons and altered suppression tactics – due in large part to the impact of climate change on the boreal forest (Calef, Varvak, & McGuire, 2017; Kohley, 2017). These changes could have significant impacts on community participation in fall subsistence hunting and, therefore, food security levels. With high rates of Rural Alaska food insecurity and concerns over continued participation in subsistence food harvesting, this research on the relationship between firefighting and subsistence, and its potential changes due to climate changes, is both timely and vital (Kofinas, BurnSilver, Magdanz, Stotts, & Okada, 2016).

The relationship between firefighting and total subsistence harvest – not just fall subsistence hunting – has been identified as needing additional research, due to the nature of the system, which involves multiple positive and negative feedback loops (Chapin et al., 2008). This research explores, quantitatively and qualitatively, the relationship between Type 2 firefighting, seasonal firefighting hand crews, and subsistence harvest with a particular focus on fall subsistence moose hunting outside of Southeast Alaska. This research further investigates through interviews and surveys, the relationship between Type 2 firefighting and fall subsistence hunting and if at any point these activities transition from being complements to substitutes. This specific facet of subsistence resource harvesting is of particular importance because it stands to be the most impacted portion of subsistence by a lengthening fire season that keeps firefighters away from their communities into the fall hunting season. With the typical hunting season about one month in length (i.e., September), firefighters could potentially miss a significant portion of the hunting season if dispatched in the fall (State of Alaska, 2017). If a crew was dispatched on a long assignment, or was dispatched more than once, they could easily miss the entire season.

Some Rural Alaska regions and communities have high subsistence participation rates or reliance on the fall subsistence hunting harvest (Fall, 2014; Kofinas et al., 2016). As such, the results of this research will matter more to these communities than those less reliant on fall subsistence hunting. Fewer hunters available for the fall hunting season –

due to responding to fall fire dispatches – could have significant negative impacts on subsistence harvest levels, if their typical harvest level is not replaced by other hunter(s) in the household or community that are willing to provide for the firefighters' households.

Reduced levels of fall subsistence hunting would result in increased reliance on expensive market foods. Income from increased firefighting could allow Rural Alaskans to replace subsistence harvested meat with market purchased meat and other foods. On average across Alaska, approximately 40% of all protein consumed by Rural Alaska communities comes from large land mammals (e.g., moose (*Alces alces*), caribou (*Rangifer tarandus*)), with some communities and regions relying more on fall hunted large land mammals to meet a high percentage of their protein needs (Fall, 2014).

2.1.2 Local Interest

During in-person interviews, firefighters expressed great interest in the results of this research. Many of the firefighters interviewed – particularly high tenure firefighters – wished to be sent the results upon completion, because they are concerned with the health of subsistence and food security in their communities.

2.2 The Mixed Subsistence-Cash System in Rural Alaska

2.2.1 Rural Alaska Mixed Economies

Many of Alaska's rural communities engage in a mixed subsistence-cash economy to meet their wellbeing needs. Climate change and accompanying changes to the boreal wildfire regime will create challenges to this system at several different geographic and temporal scales, subsequently generating feedback to various parts of the system that can improve or diminish community wellbeing.

For descriptive purposes, the multifaceted system is organized into two broad categories of ecosystem and social. The Chapin et al. (2009) social-ecological system framework is used as a guide to describe the Rural Alaska mixed subsistence-cash economy (See Figure 1) (Chapin, Kofinas, Folke, & Chapin, 2009). Most broadly, the ecological system consists of the global ecosystem whose primary change agent is climate change. From there, the subsequent levels of the system decrease in geographic size and increase in the speed with which they can change. The global ecosystem is followed by the boreal forest region, which is then followed by the subsistence harvest region – defined here to mean the radius around a community in which subsistence harvest occurs (Nelson, Zavaleta, & Chapin, 2008). The forest adjacent to a community follows the subsistence harvest region, and specific household subsistence production follows the community adjacent forest. Each subsequent level of the system can change more quickly than its predecessor. For example, a subsistence harvest region can change overnight if a large wildfire burns through and consumes local vegetation; meanwhile, the entire boreal forest region will take years to transform, due to the changing fire regime caused by climate change (Chapin et al., 2008; Nelson et al., 2008; Stocks et al., 1998). The global ecosystem will be much slower to change (IPCC, 2013).

Household subsistence, and by extension community subsistence, are directly impacted by each level of the ecosystem. Subsistence is also affected by complex social networks that exist in each community. Households require capital to produce subsistence, and are thus tied to the cash economy. Social systems impact employment, cash earnings through direct employment, and policies that indirectly affect employment. Social systems and connections also impact sharing networks regarding the sharing of subsistence food and capital necessary to produce food (Kofinas et al., 2016). Through these veins, social systems directly impact a household's ability to produce or obtain subsistence foods (Chapin et al., 2009).

The organization method used to describe the social system affecting Rural Alaska mixed subsistence-cash economies is structured after the Chapin et al. (2009) social-ecological system framework (See Figure 1). The highest level of the social system is that of federal and state agencies, which are slow to change. Regional organizations – Native, Tribal and Regional corporations, groups of communities, subsistence advisory panels, etc. – follow the federal and state governance systems. Local, village, and community level variables follow the regional organizations. Each of these levels directly impacts a household's ability to participate in subsistence through the creation and enforcement of regulation, employment opportunities, cooperation in subsistence participation, and more.

2.2.2 Challenges Facing Rural Alaska Mixed Subsistence-cash Communities

Rural Alaska mixed subsistence-cash communities face many challenges, both ecological and social in nature. Three such challenges arise from climate induced changes to the boreal wildfire region due to the structure and interactions between the variables of the social-ecological system. The first of these challenges is the lengthening firefighting season. The second is increased physical requirements on forest firefighters, and the third challenge is low dispatch frequency of fire crews on the Type 2 crew rotation list (Trainor, 2006). While increased physical requirements were mentioned in Trainor's 2006 Crew Management Study, the challenges of a lengthening fire season and low dispatch frequency were themes that arose out of interviews with Type 2 firefighters.

The issues of lengthening fire season and low dispatch rates are impacted by social and ecological systems such as climate change and fire management policy decisions. Wildland firefighting is impacted by factors various scales of the system. Examples of differently scaled impactors would be climate change on the ecological side, and changes in crew training policies at the regional level on the social side (See Figure 1). Potential solutions to these challenges exists, however, the solutions sometimes create secondary or tertiary problems (Chapin et al., 2008). Policy changes are suggested by the author, and by survey respondents that decrease challenges or increase community self-determined coping mechanisms and adaptation strategies (Chapin et al., 2010; Chapin et al., 2009; Robards & Alessa, 2003).

2.3 The Ecological System

2.3.1 Large Exogenous Agents of Change

When looking at the ecology of the Rural Alaska mixed subsistence-cash system, the largest force is the global ecosystem and, particularly, global climate change (See Figure 1). The worldwide warming trends caused by increased CO_2 and other trace gases in the atmosphere have very direct impacts on subsistence; for example, through changes in the freezing of rivers used for travel and changes in weather patterns relied upon for the timing of subsistence harvests (Berkes & Jolly, 2001).

Climate change also indirectly impacts subsistence through smaller geographic scale phenomena, such as induced shifts in the circumpolar boreal wildfire regime (Soja et al., 2007). The effects of global climate change continue to trickle down the ecological system of the Rural Alaska mixed subsistence-cash system.

Lower levels of the ecological system can also create feedback to the system that impact climate change. For example, increased carbon dioxide released by large forest fires can act as a positive feedback – a feedback that amplifies the effect of a change – increasing the impact of climate change (Chapin et al., 2009). Meanwhile, increasing albedo caused by a vegetation shift from coniferous to deciduous species can act as a negative feedback – decreasing the impact of climate change (Soja et al., 2007). Although changes at lower levels affect climate change, the impact of climate change upon the lower levels, boreal region, subsistence harvest region, etc., is much larger, as represented by the size of the directional arrows in Figure 1.

2.3.2 Changes to the Boreal Region

The boreal region is also experiencing more extreme changes in response to climate change, due to its northern latitude (IPCC, 2013). The effects of climate change on the boreal region have a massive impact on Rural Alaska communities, as it is within the boreal region that community members participate in subsistence (Brinkman et al., 2016). In many cases, it is also the environment in which they earn wages through emergency firefighting.

Due to climate change, the boreal region will experience warmer temperatures; reduced permafrost; drier fuels for fires; increased deciduous vegetation; increased fire frequency, season length and severity; increasing homogenization of the landscape; and changes to animal migration patterns and densities (Soja et al., 2007; Stocks et al., 1998). Each of these changes impacts the Rural Alaska subsistence. Warmer temperatures impact animals, vegetation, and freeze up of lakes, rivers, and streams. Drier fuels, increased fire frequency, and severity and length of season impact the habitat of species that residents rely upon for subsistence, but also impact the duration of seasonal forest firefighting employment of Rural Alaska residents (Stocks et al., 1998; Wotton & Flannigan, 1993).

Reduction in average landscape age can impact habitat and browse availability for subsistence species changing how animals and humans use the land (Nelson et al., 2008).

Changes in the boreal fire regime can cause subsequent changes in the migration patterns of animals as they avoid or utilize burn scars. Reduction in forage for subsistence species can reduce harvest species availability and the productivity of nearby subsistence harvest regions. Changes to the migration patterns due to burn scar avoidance can result in species not entering the subsistence harvest region for several years to decades, depending on the species (Nelson et al., 2008). Changes in the boreal fire regime can also improve habitat for subsistence species dependent on early succession forage, such as moose. These animals can increase use of burn scars from 10-30 years post fire (Nelson et al., 2008).

2.3.3 The Impact of Climate Change on the Boreal Wildfire Regime

The impact of climate change on the boreal wildfire regime has been well-researched and is now well-documented. To fully understand the link between climate change and boreal wildfires, an extensive literature review was conducted. The goal of the literature review was to identify the seminal research on the impact of climate change on boreal forest fires. This resulted in the identification of seven pieces of research that, combined, provide the backbone of what is now understood as the relationship between wildfire and climate change.

The literature reviewed herein documents the beginning of the discussion of the impact of climate change on wildfire regimes by understanding the impact of temperature, drought, and precipitation on the area burned by wildfire (Flannigan & Harrington, 1988; Flannigan & Van Wagner, 1991). Later research forecasted the impact of climate change on wildfire regimes through increasing fire severity, area burned, and length of season (Wotton & Flannigan, 1993). As researchers built upon the work done by others, more complex, comprehensive, and specific models were developed that forecast changes in future fire danger and activity across the boreal region (Gillett, Weaver, Zwiers, & Flannigan, 2004). Researchers provide extensive evidence that not only will climate change impact wildfire regimes, but that the change has already begun and is a result of anthropogenic climate change (Gillett et al., 2004; Soja et al., 2007). Lastly, researchers pulled together interdisciplinary historical research and new methodologies to examine how wildfire regimes will continue to change with a warming climate (Soja et al., 2007).

The geographic focus of the early literature regarding boreal forest fire regimes was primarily on Canadian forests – although Siberia and Alaska were eventually included – as they have a long historical data set regarding wildfires and have experienced dramatic changes in the fire regime in the recent past (Soja et al., 2007).

2.4 Climate Change Impacting Boreal Wildfires

2.4.1 Laying the Foundation

It is now well supported and accepted among climate scientists that increased CO_2 and other trace gases in the atmosphere will impact and are impacting wildfire regimes across the world, but particularly affected are boreal forests, due to their northern latitudes. However, as with all facts, research and investigation were necessary to uncover the relationships that define this fact. Years of investigation were conducted by countless researchers, all putting together pieces of information – some small, some large, but all integral – that together demonstrates how climate change has and will alter boreal wildfire regimes.

2.4.2 Meteorological Data and Area Burned

The first foundational building block of understanding the connection between climate change and wildfires was made by authors Flannigan and Harrington in 1988. Their research revealed the link between various meteorological variables, such as temperature and precipitation, and the occurrence and areal extent of wildfire. They correlated 28 years of data on the area burned by wildfires in Canada, from 1953 to 1980, with meteorological data on rainfall, relative humidity, temperature, and wind speed (Flannigan & Harrington, 1988).

They aimed not to create prediction equations for area burned but to determine which meteorological variables were most closely correlated with the extremes of total area burned (Flannigan & Harrington, 1988). To this end, they ran multiple linear regressions on various combinations and permutations of the meteorological data against area burned.

They chose to forgo normalization of the data statistically required of the multiple regression to maintain the relationships of extreme data points (Flannigan & Harrington, 1988).

Amongst their findings were that long sequences of dry days, which they define as days with less than 1.5mm of precipitation – the threshold for precipitation that will be retained by the forest canopy – and less than 60% relative humidity have the strongest correlation to area burned (Flannigan & Harrington, 1988). The authors conclude that it is the length of the dry spell, more so than the amount of precipitation, that is important in determining area burned by wildfire (Flannigan & Harrington, 1988). While their conclusions were similar to the findings of other researchers who used the Fire Weather Index (FWI), their use of specific meteorological data gave future researchers a way to connect predicted data on climate change to wildfire regimes.

2.4.3 Public Postulation

Perhaps the most important conclusion of their research was the noted realization that the correlation of length of dry days to area burned could have significant implications for wildfires in a future potentially impacted by climate change. With this statement, Flannigan and Harrington opened the door to future research on the impact of climate change to wildfire regimes by laying the necessary corollary groundwork between weather data and forest fires through their public postulation. Their work would continue to be cited for decades as people continue to work toward accurately predicting the impacts of climate change on boreal forests.

2.5 Modeling Climate Change by Forest Stand

2.5.1 A Forest Stand Model Approach

Climate change is an interdisciplinary issue. As such, it benefits the body of knowledge to draw from all disciplines and methodologies. In Overpeck, Rind and Goldberg (1990), the future of disturbance regimes, of which boreal forest fires are specifically called out, was modeled using a forest stand growth model, FORENA, coupled with the output of a general circulation model (GCM) – a model that predicts future meteorological conditions caused by additional CO_2 and other trace atmospheric gasses. The general circulation model used by Overpeck et al. predicted increased "disturbance weather." Overpeck et al. defined summer and autumn droughts and thunderstorms as "disturbance weather" (Overpeck et al., 1990).

2.5.2 Simulation: Growing Forest Stands to Destroy Them

Overpeck et al. (1990) investigated the impact of simulated disturbances on mixed-age forests. To achieve a mixed-age stand, they grew modeled forested stands undisturbed in FORENA for 800 years. After 800 years, the stands were subjected to an increased disturbance probability of 0.01, representing a stand destroying fire every 115 years (Overpeck et al., 1990). Along with the increased probability of disturbance, Overpeck et al. adjusted a single climate change altered meteorological variable for each simulation. The authors simulated a 1℃ and 2℃ increase in temperature, and a 15 % decrease in precipitation. These simulations were conducted in coordination with and without disturbance models. Overpeck et al. (1990) found that the increase in disturbance weather had a much greater impact on the forest vegetation than the increase in climate change variables alone. They found that it was the increased disturbance, more so than the temperature and precipitation changes due to climate change, that resulted in the largest alterations to the wildfire regime (Overpeck et al., 1990).

2.5.3 Disturbance in a Climate Changed Future

Although Overpeck et al. (1990) did not forecast the amount of area burned or the increased number of forest fires due to climate change specifically, their research opened the door to the idea of increased probability of forest fires in a world changed by climate. Their work would go on to be cited over 500 times and would pave the way for other researchers to include considerations of increased disturbance in their accounts of the effects of climate change on the boreal wildfire regime.

2.6 Forecasting Increased Acres Burned

2.6.1 Objectively Modeling the Impact of Climate Change on Wildfires

In 1991, Flannigan attempted to answer his previous question of the impact of climate change on wildfire regimes. Flannigan and Van Wagner conducted the first objective research on the impact of climate change on the future of boreal wildfire regimes. They used the daily meteorological output of three general circulation models to estimate seasonal severity ratings (SSR) for the Canadian forests. Prior to their 1991 research, predictions of the impact of climate change had been primarily speculative (Flannigan & Van Wagner, 1991). Theirs was the first study to objectively use output from general circulation models to estimate future fire severity.

2.6.2 Future Increases in Area Burned

The authors used output from the three general circulation models to estimate daily severity ratings. Severity ratings were used instead of the Fire Weather Index because these ratings more accurately described the effort required to suppress fires, and was therefore more useful to fire management organizations (Flannigan & Van Wagner, 1991). These daily severity ratings were averaged into seasonal severity ratings. Seasonal severity ratings represented one of the most important factors in the determination of area burned, along with ignition and fire control activity (Flannigan & Van Wagner, 1991).

Flannigan and Van Wagner (1991) calculated a 40% increase in the seasonal severity rating for all of Canada. The authors used this calculated increase with linear regression to link historical seasonal severity ratings to areas burned. These linkages were then applied to forecasted changes in seasonal severity ratings, in order to predict area burned throughout Canada due to climate changed. With the 40% increase in seasonal severity they calculated a 40% increase in area burned as well (Flannigan & Van Wagner, 1991). Their forecasted seasonal severity ratings did show spatial variability.

2.6.3 Limitations

The spatial detail forecasted by Flannigan and Harrington (1988) was limited to the Canadian forests east and west of Lake Nipigon (49.7237°N, 88.6145°W). The study results predicted a larger increase of 46% in area burned for the forests west of Lake Nipigon, compared to the 40% for the Canadian forests as a whole (Flannigan & Van Wagner, 1991). Further research would yield more geographically detailed results and would also expand upon this geographic range.

Limitations defined by their scope resulted in the authors ignoring several other potential changes to the boreal wild fire regime that may occur due to climate change. One of these potential changes, possible increases to the length of fire season, would be further investigated by Wotton and Flannigan a few years later.

2.7 Lengthening Fire Seasons

2.7.1 Ignoring Temporal Changes

Prior to 1993, research regarding possible changes to wildfire regimes due to climate change ignored potential changes to the length of the fire season. For years, researchers focused on how climate change altered weather patterns might impact fires *within* the historically defined fire season. Wotton and Flannigan (1993) were the first to investigate how the length of the fire season across the forested regions of Canada might be modified by climate change.

2.7.2 Forecasting Across Canada

Wotton and Flannigan (1993) used output from the Canadian Climate Center's general circulation model to examine the effects of a $2 \times CO_2$ world – a scenario in which global carbon was twice the level it was in 1993. The output of the general circulation model yielded meteorological data for 61 geographical grid points across the forested regions of Canada that they then aggregated into six regions (Wotton & Flannigan, 1993). The model output consists of 10 year increments of data from 1994-2060 for a $1 \times CO_2$ scenario and a $2 \times CO_2$ scenario (Wotton & Flannigan, 1993). The two scenarios allowed Wotton and Flannigan to compare the historic length of the fire season to that of a potential future state.

2.7.3 Defining the Fire Season

The authors defined the start of the fire season to begin after three consecutive days of noontime temperatures greater than 12°C for areas with no snow cover, or three consecutive days of no snow cover in areas with significant snow cover (Wotton & Flannigan, 1993). They considered the fire season to have ended after three consecutive days of maximum temperatures of less than 5°C (Wotton & Flannigan, 1993). Using these temperature and snow cover criteria, the authors calculated the beginning and end dates of the fire seasons under the 1×CO_2 and 2×CO_2 scenarios. Using historical data and the annual data produced by the model, the 30 year average beginning and end dates were calculated for the 1×CO_2 scenario, and 10 year average beginning and end dates were calculated for the 2×CO_2 scenario (Wotton & Flannigan, 1993). These differences in the number of years averaged are a result of data availability differences between historic and predicted data.

The beginning and end dates of the fire season calculated for the 1×CO_2 scenario were validated with historical reports from fire management organizations of the beginning and end of the fire season.

2.7.4 A Longer Fire Season

The authors predicted a 30 day increase, on average, to the length of the fire season under the 2×CO_2 scenario across all Canadian forested regions (Wotton & Flannigan, 1993). The forecasted season started earlier by an average of 18 days across all forested regions and ended an average of 10 to 11 days later in the fall (Wotton & Flannigan, 1993). These changes in the start of fire season were found to be significant at the 99% confidence level for all 61 of the grid points across the forested regions of Canada, whereas the later fall end of the fire season was found to be significant at the 99% confidence interval for all but eight of the grid points (Wotton & Flannigan, 1993).

The largest increase in season length was predicted for the area roughly corresponding with the province of British Columbia, where a 51 day increase in the length of the season was forecasted (Wotton & Flannigan, 1993). The area corresponding most closely to the Yukon Territory was forecasted to have an increase of approximately 25 days in the length of its fire season (Wotton & Flannigan, 1993). In total, the authors predict an increase of 22% in fire season length between 1995 and 2060. This would roughly translate to the fire season in Alaska being an additional month longer; ending in September instead of August.

2.7.5 No Changes in Precipitation or Drought

As with all models, assumptions were made and the scope of work was carefully defined by the authors. By narrowly defining the scope of the work to include predicting only the changes in the length of fire season, the authors ignored any potential changes to the severity of wildfires during that time. Changes that might also be impacted by climate change, such as any changes in the amount of precipitation or the length of droughts, were also ignored. They did, however, suggest that if the number of fire starts and area burned were positively correlated with the length of the fire season, then more fires would burn in the longer fire seasons forecasted (Wotton & Flannigan, 1993).

Despite this early introduction of the likelihood of increased fire season length, it would be several years before these results were combined with other meteorological data to create a more holistic picture of the impact of climate change on the boreal wildfire regime.

2.8 Climate Change, Insects, and Wildfire

2.8.1 Future Wildfire from a Bug's-Eye View

Fleming and Candau (1998) approached climate change and changes in the boreal wildfire regime from the perspective of entomology. Earlier published research ignored the exacerbated impact of climate change on forests and forest fires that would occur through the impact of climate change on insects (Fleming & Candau, 1998).

Fleming and Candau utilized a process-level perspective to understand the impact of climate change on a case study insect, the spruce budworm (*Choristoneura fumiferana* Clem. [Lepitoptera: Tortricidae]). Their investigation of the impact of climate change on the lifecycle of the spruce budworm was then used to understand an important aspect of how climate change might impact wildfire regimes – through increased tree mortality due to budworm herbivory and accompanied stress (Fleming & Candau, 1998).

2.8.2 A Warmer Climate Yields More Spruce Budworms

The authors documented the lifecycle of the spruce budworm and indicated the key moments of the lifecycle that would be affected by climate change. Warmer weather caused by climate change was forecast to increase spruce budworm survival rates and increase fecundity (Fleming & Candau, 1998). Expected increases in droughts due to climate change were predicted to increase herbivory and accelerate budworm growth, as the increased sucrose content of drought-stressed trees provides superior nutrition for spruce budworms (Fleming & Candau, 1998).

Fleming and Candau (1998) posited that delayed autumn frosts forecasted by climate change models could increase the length of budworm outbreaks by limiting damage to their food stocks. The authors deduced that spruce budworms will experience higher per capita growth rates and potential increases in the northern edge of their range, due to climate change. However, Fleming and Candau admitted that they did not consider the possibility that climate change also may favor the spruce budworm's predators, which would act as a control on their population. Despite this omission, the forecasted net effect of climate change was an increase in overall spruce budworm populations and a subsequent increase in defoliation and tree mortality (Fleming & Candau, 1998).

2.8.3 Spruce Budworms Change the Boreal Wildfire Regime

An important finding of the research was that fire may become more prevalent and severe – as determined by the amount of biomass consumed in the fire – as a result of increased insect damage in the face of climate change (Fleming & Candau, 1998). The increased stress from chronic defoliation may increase the rate of host tree mortality and add to fuel loads, regardless of any additional drought-stress caused by climate change (Fleming & Candau, 1998).

The authors summarized their findings saying, "climate driven changes to the spruce budworm's outbreak cycle may contribute to shifts in the forest fire regimes" (Fleming & Candau, 1998). In determining the effect of climate change on wildfire regimes, all climate effected aspects of the wildfire system must be considered.

2.9 Updated Methods Indicate Increased Danger

2.9.1 Forecasting Across Canadian and Russian Boreal Forests

Stocks et al. (1998) made great strides in the field of climate change induced boreal wildfire regime changes when they created a model that incorporated several important potential changes to the wildfire regime that would likely result from climate change. Unlike prior research that focused on a single change to the boreal wildfire regime, such as increased fire severity, length of season, or area burned, Stocks et al. (1998) incorporated all of these potential changes into their model.

2.9.2 Updating Methodologies

In their study, the authors used the years 1980 to 1989 as their baseline for comparison to the future $2\times CO_2$ scenario. This differed from other studies that used all available fire history or fire history data that coincided with the beginning of fire suppression. They deviated from previous studies because 1980-1989 represented, at the time, the warmest decade on record for Canada and provided a good comparison for forecasted boreal wildfire conditions (Stocks et al., 1998).

Stocks et al. also compared the output of four general circulation models, increasing the robustness of the output available for their modeling of future fire conditions in terms of spatial specificity and weather parameters. Output from each of the models was generated for each of the 224 and 191 geographic grid points spanning Russia and Canada, respectively (Stocks et al., 1998). With this output, the authors calculated severity ratings, then used frequency distributions of the monthly seasonal severity ratings from across Russia and Canada during the 1980 to 1989 period to assess extreme fire potential.

2.9.3 Increasing Fire Danger Across an Increasing Area

The authors found that all four general circulation models showed significant increases in the future area subject to high or extreme fire danger, indicating an increase in fire severity and area burned (Stocks et al., 1998). Their model also forecasted an increase in the length of the fire season, confirming the findings of previous studies (Stocks et al., 1998). Stocks et al. (1998) found significant increases in the areal extent of extreme fire danger in the early fire season and forecasted that by June of future fire seasons nearly all of Siberia and western Canada would be under extreme fire danger.

In total, the authors predicted an earlier start to extreme fire danger across a larger area of Russia and Canada, and increased fire activity and area burned overall, compared to the 1980-1989 time period (Stocks et al., 1998). They forecasted more frequent and severe fires, shorter fire return intervals, and broad reductions in the average age of forest stands (Stocks et al., 1998). This research was instrumental in bringing together several aspects of the boreal wildfire regime into a single forecast of the impact of climate change on boreal wildfire regimes.

2.10 Proving Climate Changed Impacts to Boreal Wildfire

2.10.1 A Case for Climate Change

Gillett et al. (2004) set out ambitious goals in their publication; they aimed to prove climate change was anthropogenic in nature and that the observed changes in the fire regime were caused by these anthropogenic changes in the climate. Their work solidified the climate change and boreal wildfire regime change connection.

The authors correlated three types of temperature measurements, weighted, monthly, five year mean temperatures, from forested Canadian boreal regions on a 5°×5° geographic grid to the total area burned (Gillett et al., 2004). The monthly mean temperatures were weighted by the area burned in that grid location. Using this data, the authors reaffirmed that temperature was a good indicator of area burned – explaining 59% of the variance in area burned – which confirms previous research (Gillett et al., 2004).

Gillett et al. (2004) then compared the weighted mean temperatures with predicted temperatures from an updated version of the Canadian general circulation model in a 2×CO_2 scenario. The predicted weighted mean temperatures showed a trend that was consistent with the observed weighted mean temperatures, suggesting that the observed changes in temperature were a result of anthropogenically induced climate change (Gillett et al., 2004).

2.10.2 Climate Change Altered Boreal Wildfire Regimes

After making the case for anthropogenically caused climate change, Gillett et al. (2004) made the case for climate change induced alterations to the boreal wildfire regime. They accomplished this using a two-step method. First, they forecasted expected summer temperatures – May through August – and the expected variation in mean summer temperatures with and without climate change. Using total least squares regression to estimate the coefficient of internal variability, they found that the coefficient of variability on mean summer temperatures was statistically different from zero, indicating that the underlying trend of climate change was observable in the summer temperatures from the 1964 to 1999 time period (Gillett et al., 2004). The authors used the same methodology to ascertain if a signal associated with climate change could be detected in area burned. They found the coefficient of variation on area burned to be inconsistent with zero, thus indicating the presence of a detectable signal of climate change in the trend of area burned by wildfire in the Canadian boreal forest (Gillett et al., 2004).

2.10.3 Climate Change Has Arrived

The research undertaken by Gillett et al. (2004) deviated from past research by using forecasts of climate change not to understand the future, but to understand the past and present. The authors made the case through their statistical model that the changes observed in the boreal wildfire regime since the 1960's were a result of climate change. This important finding took climate change from an idea of a potential future and brought it into the present.

These findings are supported by Soja et al. in 2007, where they produced evidence of increasingly extreme fire seasons across the boreal region and fires returning to previously burned lands in shorter intervals (Soja et al., 2007). As climate change has progressed, Alaskan boreal forests have continued to experience increases in area burned, longer fire durations and an increase in ignitions since the publication of Gillett and Soja; further solidifying the impact of climate change on boreal wildfire regimes (Calef et al., 2017).

2.11 What Does it all Mean: Altered Boreal Wildfire Regimes, Fire Suppression, and Rural Alaska Subsistence

2.11.1 Economic Challenges and Altered Access

The vast majority of Rural Alaska communities participate in mixed cash-subsistence based economies (Wolfe, Scott, Simeone, Utermohle, & Pete, 2009). Residents rely upon access to natural resources for subsistence and on emergency forest firefighting as one of few income sources (Trainor, 2006). Reliance on these particular systems puts residents of Rural Alaska in a precarious position in the face of climate change altered wildfire regimes. The two greatest challenges for Rural Alaska communities regarding the interactions between climate change altered wildfire regimes, wildfire suppression, and subsistence are changes to the economic balance of the mixed cash-subsistence economy and altered access to subsistence resources.

2.11.2 Subsistence Harvest Region

The subsistence harvest region is defined as the radius around a community in which subsistence harvest occurs; this distance has previously been defined as approximately 50-150 km (Nelson et al., 2008). Global climate change and changes to the boreal region as a whole greatly affect the community's subsistence harvest regions, whereas changes to a community's individual subsistence harvest region would have little impact on climate change or the boreal region as a whole.

Subsistence resources respond differently to fire and flourish at different rates post-fire (Nelson et al., 2008). A mosaic of landscape types is necessary for subsistence, as different species thrive in habitat of varied ages post-fire (Nelson et al., 2008). It is particularly necessary for this mosaic to occur within the subsistence harvest region because communities are no longer nomadic and are not able to follow subsistence resources and occupy seasonal camps, as was historically common (Chapin et al., 2008). Increasing distances to subsistence harvest resources increases fuel costs, which have a strong impact on household subsistence harvest (Brinkman, 2017).

2.11.3 Community Adjacent Forests

The lands adjacent to communities are impacted by the larger ecological systems; however, the primary force acting upon these lands in recent decades has been from the social system (Nelson et al., 2008). The lands surrounding communities have been subject to fire suppression for decades, resulting, on average, in older aged forests. While the older forests may be useful for the harvest of firewood, Nelson et al. (2008) suggests that very few subsistence species use late successional boreal conifer forests. This results in community residents having to bypass their local forest to participate in subsistence hunting. This then contributes to increased distances traveled to participate in subsistence hunting and greater reliance on the cash economy in order to be able to purchase the additional fuel needed for this increased travel (Nelson et al., 2008).

The predominance of late successional boreal coniferous forests surrounding communities also creates an ever-increasing fire danger to the communities (Chapin et al., 2008). Decades of fire suppression have, in many cases, resulted in dense fuel loads surrounding communities that will require increasingly intense fire suppression for community safety.

2.11.4 Household Subsistence

Household production of subsistence resources is intricately tied to the ecosystem. Changes to the ecological system at any level can impact the safety of travel to harvest subsistence resources, availability and productivity of subsistence species, as well as travel distance and cost required to harvest subsistence resources (Berkes & Jolly, 2001; Brinkman et al., 2016).

There is great variety in the level of subsistence resources harvested by households in a community, with some households providing subsistence foods for many other households (Kofinas et al., 2016; Magdanz, Greenberg, Little, & Koster, 2016; Wolfe et al., 2009). In many communities, a small percentage of households – between 20 to 30% of households has been observed – contribute a large portion – 60 to 80% has been observed – of the food for an entire community; these households are referred to as “super households” (Kofinas et al., 2016; Magdanz et al., 2016; Wolfe, 1987; Wolfe et al., 2009). These trends have persisted overtime as observed by similar trends in the presence of "super households" from Wolfe's original research in 1987 and contemporary research by Magdanz et al. (2016), Kofinas et al. (2016), and again by Wolfe et al. (2009), in recent years. Household production is also strongly influenced by the social systems of Rural Alaska, which will be discussed in more detail later.

2.12 The Social System

2.12.1 The Ecological Meets the Social

According to Wotton and Flannigan (1993) and Stocks et al. (1998), the boreal wildfire season will continue to extend further into the fall as climate change progresses. More recent research and anecdotal evidence confirm lengthening seasons (Calef et al., 2017; Kohley, 2017; Soja et al., 2007). In a $2\times CO_2$ future, fire management organizations will face increasing challenges to suppressing fires that threaten life and property. Furthermore, there will be a greater need for firefighters after August (Calef et al., 2017; Stocks et al., 1998; Wotton & Flannigan, 1993).

Rural Alaska residents that participate in forest firefighting will likely have to choose between continuing to earn income through forest firefighting or sacrificing income for participation in subsistence hunting. While wildland firefighting is not the only source of income in rural Alaska, the percent of rural Alaska community income derived from forest firefighting can be as high as 30% (Branson, 2016; State of Alaska, 1980-2015). Residents that choose to fight late season forest fires may use their income to fund subsistence hunting undertaken by other community members. Strong sharing networks at the local and regional levels in Rural Alaska would indicate that this may be a likely scenario (Kofinas et al., 2016).

However, alterations to subsistence harvest patterns and participation in firefighting are not necessarily easy to implement (Hansen, Brinkman, Chapin, & Brown, 2013). Rural Alaska residents must navigate several layers of social systems in order to engage in either activity. These social systems and their impacts on firefighters and Rural Alaska communities are discussed below.

2.12.2 Federal and State

Many of the most influential pieces of the social system come from the highest levels of government – federal and state laws and policies. This creates a scale mismatch between the level at which challenges occur and the level at which change is necessary. This is particularly challenging for effected communities because it is difficult for local agents to affect change at such a high level. The Alaska Native Claims Settlement Act (ANCSA) resulted in very limited local control of subsistence resources. Alaska National Interest Lands Conservation Act (ANILCA) provides some subsistence rights to Rural Alaska mixed subsistence-cash communities (Ristroph, 2016b). These rights are, however, not for Native Alaskans – who traditionally depended on this way of life – but for any residents of areas of Alaska deemed rural, which has changed several times in some regions of the state. This residency requirement means that former residents of Rural Alaska mixed subsistence-cash communities are unable to participate in subsistence when visiting home if they moved to an urban area for work or education, potentially creating cultural disconnection and loss of traditional hunting opportunities (Alaska Administrative Code, 2000).

Sharing networks – regular and economically necessary at the local level – exist at both the national and statewide levels (Baggio et al., 2016; Kofinas et al., 2016; Wolfe, 1987). This largescale sharing can help bridge the cultural disconnect faced by individuals who move outside of subsistence areas (Baggio et al., 2016; Kofinas et al., 2016; Wolfe, 1987). While urban residents cannot return to rural Alaska and participate in subsistence food production, they can participate in sport hunting and fishing. Sport hunting and fishing can also help repair potential cultural disconnection (Ristroph, 2016a).

Federal and state land ownership, and differing regulations regarding subsistence, create a patchwork of subsistence laws and regulations which make participating in subsistence challenging. Complex regulations increase the costs of subsistence through increased permitting requirements and increased likelihood of inadvertent regulation transgressions, due to lack of knowledge regarding landownership in the vast wilderness-like regions of rural Alaska. The patchwork of land ownership can result in limited access to Native or State of Alaska owned lands, when such access requires travel through federal land. Such access, while required by the Alaska National Interests Lands Conservation Act (ANILCA), is often problematic, resulting in increased costs of navigating around federal lands when possible or increased risks of receiving citations for traveling through federal lands ("ANILCA," 1980; Ristroph, 2016b).

Those who rely upon subsistence must navigate through these laws in order to participate legally in this traditional, customary, and often economically necessary way of life. Subsistence harvesters can be unware of crossing over land ownership lines and often have to carry both federal and state permits and applicable licenses when harvesting subsistence resources to ensure compliance (Ristroph, 2016b). The myriad of complex laws and regulations regarding subsistence harvest impact the lower levels of the social system. These regulations, which are different for federal versus state lands, dictate bag limits – how much of a resource an individual can harvest – and they dictate how many people an individual can hunt for, therefore constraining the harvest for the entire community (Ristroph, 2016b). Fishing regulations, unlike hunting, are such that households and communities can fish communally and compensate for firefighter absences during the fishing season (Alaska Administrative Code, 2000).

Federal and state policies also impact Rural Alaska mixed subsistence-cash communities through policies governing fire suppression. Within the state of Alaska, the federal and state fire management organizations, such as the Bureau of Land Management and the State of Alaska Department of Forestry, cooperate to efficiently manage fires across the vast landscape through the Alaska Interagency Coordination Center and Alaska Fire Service. These organizations are employers of emergency firefighting crews and set the policies regarding fire suppression (Alaska Wildland Fire Coordinating Group, 2010).

In this capacity, the federal and state fire management organizations impact the amount of firefighting employment available to communities and individuals. For approximately 50% of emergency firefighters that live off the road system, forest firefighting is their only wage earning job (Trainor, 2006). Research has continued to demonstrate firefighting's direct impact on the health of household subsistence harvest. In recent research by Brinkman et al. (2017), 39% of household's stated firefighting employment had a strong impact on their subsistence harvests, with another 16% citing a moderate impact. Fire management organizations set employment requirements and determine the rotation – the order in which crews are called to fires – of fire crews from Rural Alaska mixed subsistence-cash communities (Alaska Wildland Fire Coordinating Group, 2016).

The fire management organizations determine the fire suppression plan for lands across the state of Alaska; these decisions dictate on which lands fires will be suppressed and on which lands fires will be allowed to burn unimpeded (Alaska Wildland Fire Coordinating Group, 2010; Stocks et al., 1998). Lands are put into four categories for suppression – critical, full, avoid, and non-sensitive. On those lands, four management options are used – critical, full, modified, and limited (Alaska Wildland Fire Coordinating Group, 2010). The designation of land into each category depends upon the distance from a community, structures on the land, whether the fire occurs near the beginning or end of the season, and more (Alaska Wildland Fire Coordinating Group, 2010).

2.12.3 Regional

The regional level is directly impacted by the federal and state levels. Organizations such as regional Native and Tribal organizations impact employment through training of emergency firefighters in collaboration with federal and state fire management organizations and direct wildland firefighter employment in regional organizations (Trainor, 2006). These organizations often offer non-firefighting employment in communities as well.

At the regional level, a mixed subsistence-cash economic structure dominates and the social ties of the mixed subsistence-cash system become evident. The sharing of subsistence resources occurs frequently across communities, involving entire regions in the collective production and consumption of subsistence (Baggio et al., 2016; Kofinas et al., 2016). "Super households" are often community and even regional hubs of subsistence food sharing (Baggio et al., 2016; Kofinas et al., 2016). Sharing by non-firefighting households to firefighting households can mitigate the household level impact of firefighter absences due to dispatches.

Recent findings indicate the importance of individual households in the network of community, regional sharing, and interconnectedness. High levels of regional connectedness can be a result of a few exceptionally connected households within the region (Baggio et al., 2016). This dependence on a few households for subsistence foods and regional connectedness could make entire regions vulnerable to decreased food security and social connectedness in the event that these few households become unable to participate in subsistence (Baggio et al., 2016).

2.12.4 Local, Village, and Community

At the local, village, or community level, high levels of cooperation and sharing are the defining features. Employment opportunities are rare, but important, in helping fund subsistence participation by other members of the community. Similar to the regional level, "super-households" are of key importance to the food security and social connectedness of the community (Baggio et al., 2016; Kofinas et al., 2016; Wolfe et al., 2009).

These high producing "super households" tend to have older heads of household, multiple hunters, and a regular source of income (Kofinas et al., 2016). One indicator of the importance of these households is that although they have high harvest levels, they do not have high self-provisioning levels; most of the subsistence food they harvest is given away (Kofinas et al., 2016). A recent study by Baggio et al. (2016) found that in three communities in Rural Alaska, between 64 and 80% of all subsistence foods in a community are the result of sharing within that community. Chapter 3 discusses how this "super household" phenome relates to firefighting households.

Employment is of the utmost importance in the mixed subsistence-cash community due to its necessity in facilitating participation in subsistence. Cash is needed for everything from bullets to gasoline (Chapin, et al. 2008).This need for cash is underscored by research indicating that all high-harvesting households have at least one household member that earns a cash income (Kofinas et al., 2016). Emergency firefighting employment is an important source of income, as it is only available, on average, for four months of the year. This leaves the rest of the year to participate in subsistence, making it an ideal occupation for members of self-reliant and "super households" that harvest subsistence resources available during the fall and winter seasons.

2.12.5 Substituting Away from Subsistence

Economic modeling of the community using a Becker-type household production model indicates that as firefighting income increases, time devoted to subsistence will decline. Higher potential wages from forest firefighting increase the marginal cost of time-intensive subsistence food production, relative to market food production (Eatwell, 1987; Huffman, 2010). Increased wage potential results in a larger opportunity cost of time spent participating in subsistence activities.

Reductions in subsistence activity, and accompanying increases in purchased market foods, could impact food security, nutrition, and cultural cohesion and identity as subsistence hunting has significant cultural importance in many communities of Rural Alaska (Brinkman et al., 2014; Kofinas et al., 2016).

Difficult decisions regarding time allocation between forest firefighting and subsistence will be one of the greatest challenges to the continued health of traditional and customary subsistence practices in Rural Alaska. An equally vexing and potentially compounding challenge to the subsistence wellbeing of Rural Alaska residents will be the problem of altered access to subsistence resources (Brinkman et al., 2016).

2.13 Adapting to New Regimes

As shown by Gillett et al. (2004), climate change has already altered boreal wildfire regimes and will continue to change the length, severity, and total area burned according to predictions by the other authors cited herein (Gillett et al., 2004). Adaptation to new fire regimes will be necessary for fire management organizations and Rural Alaska communities that depend on these mixed cash-subsistence systems for their wellbeing. Estimating future changes to the boreal wildfire social-ecological system, as carried out in the coming chapters, can help both of these groups. Fire management organizations will be able to plan suppression efforts, budgets, and personnel needs. Rural Alaska communities can use forecasted scenarios to plan for successful transitions to new future, while a lack of planning could result in low rates of community persistence and an overall decline in community well-being.

Chapter Three: Firefighters, Subsistence, and Policy

Abstract

Many rural Alaska communities have mixed cash-subsistence economies in which people have to balance their time between earning an income and harvesting subsistence foods. Cash income is necessary to pay for things such as electricity, ammunition, and other capital necessary to engage in subsistence. Harvesting subsistence foods requires large investments of time. Altered fire regimes due to climate change are projected to result in more fires and longer seasons, increasing opportunities to earn income and decreasing time available for fall subsistence hunting. This paper seeks to understand the current status of firefighters who engage in subsistence, current behaviors that firefighters use to balance firefighting and subsistence and future adaptations firefighters will use as climate changes lengthens the fire season and creates potential conflict between subsistence hunting and firefighting. Utilizing surveys and interviews of Type 2 Wildland Firefighters, firefighters indicated that they would always accept firefighting assignments and that food sharing is the main behavior utilized to balance firefighting and subsistence harvesting. Firefighters also indicated that in the future, their communities would continue to meet subsistence needs regardless of a lengthening fire season. Potential policy changes that would increase community capacity to adapt are suggested such as increasing the length of hunting seasons and instituting community bag limits and restricting wildland firefighting management use of “closest available resources”.

Introduction

3.1 Firefighting Background

There are over 50 rural Alaska communities which serve as a base for Type Two wildland fire crews. These crews are typically used to ensure complete suppression of fires (Kohley, 2017). These crews are predominately staffed by Alaskan natives. State and Federal fire management organizations (i.e. Bureau of Land Management) are responsible for the hiring, training and dispatch of these crews.

Type two crews operate on a rotation schedule. Fire management organizations set employment requirements and determine the crew rotation – the order in which crews are called to fires – for Type Two crews (Alaska Wildland Fire Coordinating Group, 2016). The crew at the top of the list is dispatched to a fire, and upon completion of that assignment, they are put at the bottom of the list (Alaska Wildland Fire Coordinating Group, 2016). The second crew then moves to the top of the list and will be the next dispatched to a fire (Alaska Wildland Fire Coordinating Group, 2016). If a crew is unable to accept a dispatch when they are at the top of the list, they are moved to the bottom of the list without being dispatched (Alaska Wildland Fire Coordinating Group, 2016). A crew must be dispatched for a minimum of three consecutive eight hour shifts before being moved to the bottom of the list (Alaska Wildland Fire Coordinating Group, 2016). While most of these crews accept dispatches only within Alaska, several rural Type Two crews per year will accept dispatches out-of-state; a larger crew – 20 people versus 18 – is required in order to be dispatched out of state (Alaska Wildland Fire Coordinating Group, 2016; Branson, 2016).

The economic impact of firefighting on Rural Alaska and challenges resulting from that dependence are well documented by Trainor (2006). Many of the communities with rural Type II crews rely heavily on subsistence harvests to meet their nutritional needs (Branson, 2016; Fall, 1990, 2014). Research on the impact of firefighting on subsistence is limited. For 50% of rural Alaska firefighters firefighting was their only source of income (Trainor, 2006). Crew members indicated that wages from firefighting were used to purchase hunting and fishing supplies for subsistence among other things (Trainor, 2006).

Chapin et al. (2008) broaden this discussion, laying out relationships between climate change and its impacts on wildfires and subsistence, albeit separately. Noting that Type II crews would be impacted by longer fire seasons, Chapin et al. (2008) separately evaluate the impact of climate change on subsistence through the destruction of habitat (Chapin et al., 2008). While Chapin et al. (2008) discussed the impact of climate change on rural Type II firefighters and subsistence, the authors stopped short of discussing the tertiary impact of climate change on subsistence harvest through its impact on firefighting.

As climate change extends the length of the fire season, potentially causing it to overlap with the fall subsistence hunting season, the question of how firefighting impacts subsistence, now and in the future, becomes of increasing interest (Calef et al., 2017; Chapin et al., 2008; Soja et al., 2007). Subsistence harvesting seasons are strictly regulated by state and federal entities and must be adhered to by rural Alaska residents (Ristroph, 2016b). This historic seasonal pattern allowed firefighters to earn income and still produce significant amounts of subsistence foods. It is the goal of this paper to connect the economic and social aspects of firefighting and subsistence in order to understand current and future methods employed by firefighters to manage conflicts between firefighting and subsistence. This information will then be used to better understand how subsistence food production might change if the fire season overlaps the fall hunting season.

Data drawn from a survey and qualitative interviews with crew bosses and crew boss trainees from rural Alaska are used to evaluate the behaviors firefighters utilize in order to continue engaging in the harvest of subsistence resources and firefighting. It also goes one step further in projecting how the relationship between firefighting and subsistence will change over time as climate change alters the boreal wildfire regime and with it the timing of firefighting crew dispatches and associated wages (Kasischke & Turetsky, 2006).

3.1.1 Importance of Social Connections

In rural Alaska communities sharing networks are part of the social system, cross several levels, and include food, capital, but rarely cash (Kofinas et al., 2016). For example, sharing networks operate within communities, within regions, and occasionally across federal boundaries as in the case of sharing subsistence resources with Canadian First Nations (Kofinas et al., 2016). Through these veins, federal and state policies and regulations impact a household's ability to obtain or share subsistence foods (Chapin et al., 2009)

There has been significant research into the importance of social networks in subsistence-cash economies (Baggio et al., 2016; Kofinas et al., 2016; Magdanz et al., 2016; Magdanz, Koster, Naves, & Fox, 2011). It should be expected that the sharing and labor substitution which results from community networks – are critical to maintaining the ability of rural Alaska citizens to engage in firefighting.

3.1.2 The Social-Ecological System

Climate change and the accompanying changes to the boreal wildfire regime will create challenges to the mixed-cash economy system at several geographic and temporal scales, generating feedback to various parts of the system that can improve or diminish community wellbeing (Fig. 1). The multifaceted system has been organized into two broad categories of ecosystem and social. For summary purposes, the ecological system consists of the global ecosystem whose primary change agent is climate change. From there, the subsequent levels of the system decrease in geographic size and increase in the speed with which they can change.

The global ecosystem is followed by the boreal forest region, which is then followed by the subsistence harvest region – defined here to mean the radius around a community in which subsistence harvest occurs (Nelson et al., 2008). The forest adjacent to a community is one level below the subsistence harvest region, and specific household subsistence production is one level below the community adjacent forest. Each subsequent level of the system can change more quickly than its predecessor. For example, a subsistence harvest region can change overnight if a large wildfire burns through and consumes local vegetation; meanwhile, the entire boreal forest region will take years to transform, due to the changing fire regime caused by climate change (Chapin et al., 2008; Nelson et al., 2008; Stocks et al., 1998). The global ecosystem will be much slower to change (IPCC, 2013).

Household subsistence, and by extension community subsistence, are directly impacted by each level of the ecosystem. Subsistence is also affected by a complex social networks which exist in each community. Households require capital to produce subsistence, and are thus tied to the cash economy. The federal, state and local levels of the social system impact employment and cash earnings through direct employment and policies that affect employment. Federal and state levels also impact subsistence thought subsistence harvest policies.

3.1.3 Policy Challenges

Additional challenges to the mixed cash-subsistence economy arise from policies and regulations of high level social system, state, and federal governments. Two challenges addressed herein are the lengthening firefighting season and low dispatch frequency of fire crews on the Type II crew rotation list (Trainor, 2006). The challenges of a lengthening fire season on firefighting resources was also mentioned by Flannigan (1991) when discussing the impact of climate change on the boreal wildfire regime. Each of these challenges is impacted by social and ecological systems and at various scales.

3.1.4 Mixed Cash-Subsistence Economies

Many rural Alaska communities have mixed cash-subsistence economies in which people have to balance their time between earning income and harvesting subsistence foods (Baggio et al., 2016; Chapin et al., 2008; Kofinas et al., 2016). Cash income is needed to cover expenses for housing, electricity, gasoline, guns, ammunition, and other capital necessary to engage in subsistence. Harvesting subsistence foods requires large investments of time but is less expensive to produce than market foods. Subsistence also holds significant cultural value outside of its economic importance. Further challenges include a relative lack of employment opportunities and high rates of unemployment in many rural Alaska communities (Shanks, 2013). Wildland firefighting has been an attractive employment option due to its seasonal nature which affords firefighters time for subsistence food harvest and its availability as entry level employment (Chapin et al., 2008). Traditionally, firefighting employment for rural Type II crews has ended in August, prior to fall subsistence activities.

Altered fire regimes due to climate change could result in more fires, longer seasons and increased opportunities to earn income from wildland firefighting (Fleming & Candau, 1998; Gillett et al., 2004; Kasischke & Turetsky, 2006; Soja et al., 2007). Increased time devoted to firefighting will decrease firefighters' time available for harvesting subsistence resources. Climate change altered wildfire regimes will invariably impact travel required to produce subsistence harvest through decreased biological productivity as well (Brinkman et al., 2016; Gustine et al., 2014).

Subsistence is not just culturally significant, but economically necessary. It's estimated that approximately 189% of rural Alaska residents' protein needs comes from subsistence foods (Fall, 2014). Market foods are expensive and incomes are low (McDowell, 2009; Shanks, 2013). Given the high price of store bought foods, decreased subsistence food production would translate into threats to residents' food security. It is also possible, however, that through community cooperation, labor substitution and planning decreased participation rates may not result in decreased food production.

Firefighting has historically occurred during the fishing season, which is a community-wide harvesting activity, and ended before the fall hunting season (Sobelman, 1985). The communal nature of subsistence fishing is more complementary to firefighting than hunting because other community members can and do readily fish in place of firefighters when they are called to a dispatch. Also, the use of fish wheels increases productivity while decreasing the amount of labor necessary. Not as many community members participate in hunting as in fishing, so there are fewer people able to step in and hunt in the place of firefighters' if they are dispatched during the hunting season. Hunting and firefighting are two activities that tend to be engaged in more frequently by men as opposed to women, which potentially leads to fewer opportunities for labor substitution (Sobelman, 1985; Trainor, 2006). Men are also larger contributors to the flows of subsistence goods making their potential absence for firefighting a significant risk to food security (Kofinas et al., 2016).

Extensive subsistence sharing networks help mitigate risks to food security for those in the community who are unable to be self-sufficient in their subsistence food production (Baggio et al., 2016; Kofinas et al., 2016; Magdanz et al., 2011). Sharing and reciprocity are important factors in the function of rural Alaska Native mixed subsistence-cash economies (Kofinas et al., 2016; Magdanz et al., 2016). Kofinas et al. (2016) estimate sharing networks accounted for 60-75% of all subsistence food inflows into households in studied communities and that social networks were responsible for 66-75% of subsistence food production and distribution. Changes to Alaska's fire season due to climate change has the potential to alter the complementary nature of subsistence food production and firefighting (Soja et al., 2007).

Ultimately, the impact of increased fire season length and associated absence of firefighters during the fall hunting season will most likely be directly related to the remaining community members' ability to replace the harvest of those firefighters. All else being equal, a community that is able to replace the missing subsistence levels of their fire crew will not suffer a communitywide decline in subsistence harvest levels, while a community that is unable to replace the harvest of the absent fire crew will suffer communitywide declines in subsistence. The makeup of the fire crew therefore determines the communitywide impact to subsistence levels of the increased fire season length.

Methods

3.2 Survey and Interview Methodology

3.2.1 Study Area

Surveys and interviews were conducted 30 and 16 Type II wildland firefighters respectively from across Rural Alaska (Fig. 2). The Rural Alaska region was the focus of the study due to the presence of mixed-cash subsistence economies that include wildland firefighting as a significant source of income (Trainor, 2006). Firefighters from Rural Alaska are able to engage in subsistence harvesting which was the focus of this research (Alaska Administrative Code, 2000). Participation in subsistence was a requirement for participation in surveys and interviews.

3.2.2 Surveys

To better understand how firefighters balance firefighting and subsistence now and in the future, surveys and interviews were conducted with current Type II firefighters. The surveys and interviews covered economic and social elements of firefighting and subsistence such as earnings, firefighting tenure, cash spent on subsistence, subsistence productivity, sharing etc. (Fink, 2017; Trainor et al., 2009).

Structured, questionnaire-style surveys were conducted between May and August of 2017. The survey included 22 questions which asked for their experience firefighting, including timing of dispatches and income earned, questions regarding subsistence, including time spent moose hunting and the size of their hunting party, and questions regarding the impact of a longer fire season on their fall subsistence hunting. Firefighters were also asked about the size of their household. Firefighters were allowed to interpret the meaning of household as they saw fit unlike previous research which specified permanent household membership. It is possible that firefighters define household as a set of kinship relationships rather than the number of people occupying the same dwelling.

In-person surveys were conducted during the 2017 bi-annual Alaska Crew Boss Academy in Fort Wainwright, Alaska. Printed surveys were completed by Type II firefighters and crew bosses in attendance at the academy. Twenty-six surveys were completed by those firefighters in attendance. Survey respondents self-selected. In total, five respondents had prior experience as crew bosses and 25 were crew members. Out of the 25 crew members responding, 22 were in training to become crew bosses.

These firefighters surveyed represent a sample of the overall population of interest, Rural Alaska Type Two wildland firefighters. Printed surveys were completed by Type II firefighters in attendance at the bi-annual crew boss academy (Fink, 2017). Twenty-six surveys were completed by those in attendance (Berg & Lune, 2012; Fink, 2017).

Online surveys, identical to those printed for the Crew Boss Academy, were posted online in May 2017 (Fink, 2017). Firefighting trainers and Zone Coordinators were used to increase the number of firefighters responding to surveys and generate equally representative geographic survey responses (Fink, 2017). Online surveys were received from May through August. Five responses were received through the online system. Surveys completed online were compared to previously completed surveys to avoid duplicate responses and insure separate identity of respondents (Fink, 2017).

3.2.3 Interviews

Sixteen semi-structured, in-person interviews were conducted during the 2017 Alaska Crew Boss Academy in Fort Wainwright, Alaska. Out of 26 participants at the academy 16 were interviewed. The recruitment process consisted of a verbal introduction of the project and request for survey and interview participation by the author. This request for participation was repeated approximately three times daily during breaks in firefighter training by the author and academy instructors over the course of seven days. Interviews were often conducted in conversational style that respondents felt most comfortable with.

The ability to conduct these interviews in a "natural setting" – firefighters engaging in firefighting activities – helped to expand formal interviews with numerous supplemental conversations that further informed the interview questions (Mack, Woodsong, MacQueen, Guest, & Namey, 2005; Patton, 2001). A full list of interview themes and responses can be found in Table 1.

3.2.4 Supplemental Conversations

Along with explicit survey and interview questions, field observation and conversation were used to supplement interviews and surveys (Creswell, 2007; Patton, 2001). This methodology was used in situations where short timeframes made long interviews unrealistic. This method included asking one or two interview questions at a time while interacting with a firefighter, or observing a group of firefighters' reactions to another firefighter's response to an interview question (Creswell, 2007; Mack et al., 2005; Patton, 2001). Group responses were not reported in interview results, but were used to help identify themes by which the interview notes and transcripts were coded in Excel. There were 14 supplemental conversations that took place during the Crew Boss Academy.

Prior to the first conversation with an individual, I introduced myself, explained the purpose of my research and wrote notes about the conversation as soon as possible, following the guidelines outlined in Mack (2005). I then included these notes in the interview forms according to the interviewee and interview questions discussed (Patton, 2001). These conversations brought up several themes that were not originally intended to be included in the research but appeared potentially important due to their repetition. The analyses of the interviews were comprised of pre-determined themes and emergent themes guided by interview respondents.

3.2.5 Data Management Methods

Interviews and conversations were transcribed and coded by themes including those identified during supplemental conversations (Berg & Lune, 2012; Patton, 2001). Respondents were coded by tenure in the profession of wildland firefighting and status as a provider, recipient or both of subsistence foods within their community (Berg & Lune, 2012). Occupational tenure categories were developed to give each category three or more respondents and a ten year or larger time span. To ensure a relatively equal distribution of firefighters in each strata three job tenure categories were used: 0-14 years, 15-24 years, and 25 or more years.

Status as a primary provider or recipient was determined and coded by an interviewee's response to several questions. To be classified as primarily a provider of subsistence foods an interviewee must have explicitly stated that they hunt or fish for someone else and that they share(d) subsistence foods with others. To be classified as primarily a recipient of subsistence foods an interviewee must have explicitly stated that someone else hunts or fishes for them and that they receive(d) subsistence foods from others. Interviewees that stated they both gave and received subsistence foods that they hunted or fished for another, and another hunted or fished for them were categorized as "both."

The number of similar responses to interview questions were coded into Excel where percentages of each response were calculated. For example, when asked if they hunted, all positive responses were coded with a one and all negative responses were coded with a zero. This was repeated for each theme and each firefighter's response where answers could be coded discretely. Survey questions with continuous variable responses such as wages were averaged in Excel.

Results

3.3 Survey and Interview Results

Firefighters that participated in the survey had on average been fighting fire for 17 years. (Table 2.) Seventy-five percent of firefighters had family ties to wildland firefighting, and 88% started fighting fire because it was the only job available in their community. Average firefighter household size was four people with a maximum household size of 10 people and a minimum of one. All but two of the individuals surveyed were male, and all firefighters surveyed or interviewed engaged in subsistence. The small sample size for surveys, 30, and interviews, 16, limits the generalization of findings to the specific communities represented by the respondents.

On average, surveyed firefighters were dispatched four times per year, and stopped fighting fire in August. While the highest firefighting wage earned in the prior year was \$38 000, average earnings in the same year were \$9715. For seven percent (2) of firefighters, wages from firefighting comprised 75-100% of their household's income. Twenty-one percent (6) of firefighters reported that their wages made up 51-75% of household income in 2016. While the percent of household income made up of firefighting wages will undoubtedly vary from year to year as the number of dispatches changes, these results are consistent with prior results (Trainor, 2006) which indicate that 50% of firefighters' household income comes from firefighting wages. Further corroboration is provided by Alaska Department of Fish and Game data which suggests that indicates that average household income for the communities represented in the sample was \$37 262 in 2015 resulting in an firefighting wages equaling 26% of the average household income (Branson, 2016; State of Alaska, 1980-2015).

Looking toward the future, 27% (8) of surveyed firefighters anticipate decreased amounts of subsistence harvested foods in their communities if the fire season continues to lengthen due to their absence during the hunting season. Along with potential decreases in subsistence harvested foods, 31% (5) of firefighters interviewed stated that they would purchase more food from the store if the fire season kept them away from the fall subsistence hunting season. Sixty six percent (19) of surveyed firefighters stated they would forgo hunting to fight fire.

When it comes to subsistence, fishing and large land mammal hunting were the primary focus due to the high levels of current and future time conflict anticipated and reported. Seventy-five percent (23) of surveyed firefighters stated that they currently subsistence fish or hunt around their fire schedule. Information from in depth interviews indicated that this was only possible for some firefighters that have productive fishing or hunting grounds within a short distance of their communities. Other firefighters were unable to fish or hunt while waiting for a dispatch call, because they would be unable to return to their community in time to respond to the call.

High levels of sharing of subsistence foods and gear necessary to harvest food was reported by all interviewed firefighters with 94% (15) of firefighters mentioning sharing of food. The acceptance of food was more common, at 81% (13), than food giving, at 63% (10). Those firefighters that mentioned giving food to other households indicated that they typically shared with many households and shared large quantities of food with them.

Gear – guns, four wheelers, and radios – were shared at a much reduced rate, with 31% (5) of interviewed firefighters indicating that others shared gear with them and only 13% (2) indicating they shared their gear with others. In terms of reciprocity, 44% (7) of firefighters indicated they do or would purchase fuel for someone who shared subsistence foods with them if they were away on a fire dispatch.

3.3.1 Current Conflicts with the Firefighting System

Ninety seven percent (29) stated that firefighting conflicted with their subsistence harvest. Firefighting can conflict with the harvest of one or more species depending on the timing of fires and whether or not those assignments are in or out-of-state. Different geographies within Alaska also have different seasonality and traditional harvest species available, which create more subsistence conflicts for some firefighters and fewer for others.

The most frequently cited conflict was with fish harvesting, with 57% (17) of all survey respondents reporting that conflict due to the seasonal overlap. At present, firefighting conflicts with moose hunting for 40% (12) of the firefighters surveyed. These conflicts indicate that firefighters already have methods of coping with conflict to meet their household and community subsistence needs.

However, despite having methods in place for coping with conflicting subsistence and firefighting seasons, 67% (of firefighters surveyed stated that a fire season lasting only four weeks longer than is typical would make meeting their subsistence needs more difficult, with 30% stating this longer fire season would make meeting their subsistence needs "much more difficult" (fig. 3).

3.3.2 Current Behaviors Balancing Firefighting and Subsistence

When it comes to fishing, 63% (19) of firefighters reported that they expect that someone else in their community will be able to fish or hunt for them if they missed the subsistence harvest season due to firefighting (Table 3). All firefighters interviewed reported that they can easily find fishing opportunities within a one to two-mile radius of their house. When it comes to moose, firefighters surveyed for this research indicated that harvesting a single moose takes anywhere from five to 125 hunter-days, which were calculated by the total number of days spent hunting multiplied by the size of the hunting party. Moose hunting is most frequently carried out by groups of men. The average number of hunter-days required was 32 for a single moose.

In years with fewer fires, 23% (7) of survey respondents stated that they would take fewer trips to harvest subsistence resources. These findings support Brinkman et al. (2014), who reported that in response to high fuel prices, hunters decreased the number and distance of subsistence hunting trips. In more recent research, Brinkman. (2017) found that 51% of subsistence practitioners strongly agreed that fuel or energy costs challenge their household's ability to conduct their traditional harvest practices.

Thirty one percent (9) of firefighters stated that high fuel prices would make them more likely to accept firefighting assignments during their hunting season – further emphasizing the importance of purchased inputs such as gasoline in subsistence cash economies (Brinkman et al. 2014; 2017).

The primary response to decreased firefighting wages identified by survey respondents was to increase time devoted to subsistence, which supports research by Berman (1998) and general household economic theory. This theory states that time devoted to work increases as wages increase, and time devoted to household activities, which we take to include subsistence activities, increases as wages decrease (Berman, 1998; Eatwell, 1987).

Hunting during the winter subsistence harvest season was cited by 31% (5) of firefighters as their choice anticipated coping mechanism for a lengthening fire season. Firefighters stated that the reason they do not currently hunt during the winter season is because it is more dangerous and more difficult than hunting in the fall. Despite potential difficulties associated with maintaining subsistence during a longer fire season, 94% (28) of firefighters state they would always accept firefighting assignments.

3.3.3 The Necessity of Adaptation

Income earning opportunities in many parts of Rural Alaska are extremely limited (Chapin et al., 2008; Shanks, 2013; Trainor, 2006). The survey conducted here corroborates previous research in finding that 88% (14) of all firefighters interviewed chose firefighting because it was the only income earning opportunity. Of those, firefighters from non-roaded communities, 91% (13) stated that firefighting was the only income earning opportunity for them in their communities.

Survey and interview results indicate that firefighters intend to continue adapting to changes in the firefighting system in the future and maintain firefighting employment as an essential part of their livelihood. All but one firefighter surveyed stated that they were willing to work two or more additional weeks past the typical end of the season, which is August and September for over 88% (26) of survey respondents.

3.3.4 Fighting Fires, Forgoing Hunting

A four week extension to the fire season would create a significant conflict for moose hunting. Forty-percent (12) of firefighters surveyed currently experience a conflict between firefighting and moose hunting. The proportion of respondents indicating a time conflict would increase to 77% (23) if the fire season were four weeks longer.

When asked how or if they would alter their fall hunting to accommodate fighting fires into the autumn due to climate change, 94% (15) of interview respondents and 66% (20) of survey respondents stated that they would accept firefighting jobs into the fall, even if it meant they could not hunt at all. All crew boss respondents stated they would be willing to forgo hunting in order to continue firefighting. These findings substantiate previous findings regarding the importance of cash in subsistence-cash economies and scarcity of opportunities for earning cash income (Baggio et al., 2016; Berman, 1998; Brinkman et al., 2014; Kofinas et al., 2016; Magdanz et al., 2011; Sobelman, 1985). Transitioning to methods of harvesting traditional resources that require capital, such as four-wheelers and snow machines, require ongoing participation in the cash economy (Brinkman et al., 2014). This increased participation in the cash economy was noted in the North Slope Borough by Berman (1998). Robards and Alessa (2003) found that adaptation to a changing Arctic environment encouraged engagement in activities that increase geographic range for subsistence harvest.

3.3.5 Cash Sharing

Firefighters interviewed indicated that their willingness to accept firefighting employment at the expense of their own personal subsistence harvest during the fire season does not indicate a willingness to accept decreased community harvest. Seventy five percent (12) firefighters reported that they did not believe that community harvest would decrease if they were unable to participate in fall subsistence hunting.

Reciprocity is an important part of culture and economics in Rural Alaska (Kofinas et al., 2016). Purchasing gasoline for community members that assist with subsistence harvesting (sharing portions of their harvest or lending gear) is one way of expressing reciprocity. Almost half, 44% (7), of firefighters interviewed stated that they would purchase gas for someone who shared subsistence foods with them if they were unable to hunt due to a fire related absence. These responses were often somewhat reluctant, or were pondered for quite some time before answering in the affirmative. This data confirms research undertaken by Magdanz et al. (2011) who find that food is shared much more broadly than cash or cash proxies such as gasoline.

Of those interviewed, 50% (3) of junior firefighters interviewed, 0-14 years' experience, would purchase gasoline for a community member that engaged in subsistence activities on their behalf or shared subsistence foods with them. This percentage decreased to 43% (3) for firefighters with 16-24 years' experience and further decreased to 33% (1) for firefighters with 25+ years' experience.

3.3.6 Gear Sharing

One third (5) of all surveyed firefighters indicated they would share gear. Every respondent with more than 30 years of experience (3) stated that they would share their gear. While Kofinas et al. (2016) find that sharing of this type is less frequent than sharing of food, another important factor may be at play. As noted by Wolfe (1987) gear ownership determines the directionality of the sharing arrangement and impacts overall subsistence harvest levels. Four firefighters interviewed, all of whom had 0-14 years tenure, owned no gear outside of a gun and therefore were regular recipients for gear sharing and had no ability to share gear.

3.3.7 Planning Adaptations to Maintain Subsistence Levels

Of those firefighters interviewed, 75% (12) anticipate community subsistence levels would remain constant in the event of the fire season overlapping with the fall hunting season. Despite being willing to forgo hunting in order to continue fighting fires, many of these firefighters, 69% (11), plan to hunt around their fire schedules. The typical hunting season around Alaska – hunting seasons vary by geographic location – lasts for one month. Most fire assignments for rural Alaska fire crews lasts two weeks (Alaska Wildland Fire Coordinating Group, 2016; State of Alaska, 2017). Thus, if fire crews were called out to a two week long fire during the hunting season, they could hunt during the other two weeks of the hunting season. Firefighters plan to hunt close to their communities, between fire calls, or shift their hunting to the "riskier" winter hunting season. If the firefighters interviewed had to entirely forgo hunting, 88% (14) anticipate that one or more community members would hunt in their place.

Firefighters shifting their hunting to the winter season was one theme that emerged during interviews in response to questions about methods of adaptation to a longer fire season that would require being dispatched later into the fall hunting season. Only six (1) percent of firefighters interviewed currently participate in the winter hunting season. Nearly one third (5), of interviewees reported that they would shift their hunting to the winter season if they were dispatched during the fall hunting season.

3.3.8 Demographic Variations

Responses to several interview questions varied by tenure as a wildland firefighter. For example, 100% (3) percent of firefighters with 25 or more years of experience stated that someone else would hunt in their stead, but that no one could go on a fire assignment in their place. While all of those firefighters with 14 or fewer years of experience (6) stated that someone else could hunt in their place if they were absent during the fall hunting season, 17% (1) felt confident that someone else *could* replace them on a fire crew. Increased levels of experience make firefighters harder to replace. Of those firefighters surveyed or interviewed, those with longer tenure were more likely to be crew or squad bosses, which reinforced previous research indicating that crew bosses tend to be older aged workers (Trainor, 2006). Since a fire crew needs at minimum one crew boss and three squad bosses, and those with longer tenure are more likely to fill these positions, these workers *are* more difficult to replace (Alaska Wildland Fire Coordinating Group, 2016).

“Super-households” typically have older heads of household and a consistent source of income (Wolfe, 1987). Of surveyed firefighters with 25 or more years of experience, 67% (2) stated that they share foods with others in their community. More experienced firefighters were almost twice as likely to believe that their absence during the fall hunting season would result in a decrease in community level subsistence resource harvest, 33% (1), versus 17% (1) for those with 0-14 years’ experience and 29% (2) for those with 15-24 years’ experience.

Sixty-seven percent (4) of surveyed firefighters with fewer than 15 years of experience state that they give foods to others in their community, the amount of which is unknown. Of this same group of surveyed firefighters, only 17% (1) of them believed that their absence from their community would result in a community-wide decline in fall subsistence harvest. Research by Kofinas et al. (2016) argues that age was a strong predictor of the giving of subsistence foods which may be a factor in these results.

Years of firefighting experience plays a role in gear sharing with percent of firefighters reporting gear sharing increasing with tenure. This finding is supported by the life-cycle income hypothesis, which states that with increasing age we see increased income (Eatwell, 1987). This increased income could be used to purchase gear that could then be shared with others in their community. Sixty seven percent (4) of the newer firefighters interviewed indicated that they used other community members' gear, and the use of others gear decreased as tenure increased.

3.3.9 Disparities by Subsistence Food Sharing Status

Backing up repeated findings on the prevalence and importance of subsistence food sharing in Rural Alaska communities, nearly all (15) firefighters interviewed mentioned both sharing subsistence foods with others and receiving subsistence foods from others (Baggio et al., 2016; Kofinas et al., 2016; Magdanz et al., 2011). Surveyed firefighters classified primarily as providers mentioned food sharing less often than those classified as recipients or both, 50% (1) versus 100% (4 and 8) for recipients and both. Fifty percent (1) of interviewed firefighters who were providers of subsistence foods stated that someone would hunt for them if they were dispatched and unable to hunt.

Of surveyed firefighters who are predominately recipients of subsistence foods, 100% (4) reported that someone else would hunt in their stead. These respondents predominately had longer tenure. (50% (8) all firefighters interviewed reported being both providers and recipients of subsistence foods.)

These survey and interview results indicate differing opinions on the impact of fire crew absence during the fall hunting season dependent on firefighters' positions as primarily subsistence providers or recipients. Unfortunately, without knowing the average makeup of statewide rural fire crews between providers and recipients of fall subsistence harvest, there is not enough information from surveys and interviews alone to estimate the impact on communitywide subsistence levels of increased length of the fire season and absence of fire crews.

3.3.10 Increases in Market Food Purchases

Nearly one third of all firefighters interviewed, 31% (5), reported that they would purchase more food from the store if they were dispatched during the hunting season. These findings are consistent with the findings of Loring and Gerlach (2009), who found Rural Alaskans substitute market foods for subsistence foods in times of shortage. This is also consistent with the 25% (4) who anticipated a decrease in community wide subsistence harvest levels. A decrease in subsistence food production is not necessary to have an increase in market food purchases. To date, no research examining the relationship between the purchase of market foods in rural Alaska and household income levels. Assuming market foods are normal goods some increase in market food purchase would occur as income increased regardless of a reduction in subsistence foods.

Discussion

3.4 Interpreting Results

3.4.1 Current Behaviors: Labor Substitution and Sharing

The current conflict between the fishing season and firefighting is managed, according to firefighters interviewed, by subsistence labor substitution. Sixty-three percent of interviewees had household or community members who fished for them when they absent from the community due to a fire dispatch. This substitution is possible due to current subsistence fishing regulations which allow any qualified subsistence user to designate another subsistence user their proxy for the purposes of harvesting subsistence fish resources (Alaska Administrative Code, 2000). This same flexibility does not exist when subsistence hunting large land mammals such as during the fall moose hunt on state lands. State law limits proxy hunting to situations where the subsistence user is blind, physically disabled or over 65 years of age (Alaska Administrative Code, 2000). On federal lands, one hunter can designate another federally recognized subsistence hunter to hunt for them (Ristroph, 2016b). This designated hunting allows subsistence hunters on federal lands to hunt in place of firefighters who are away on a dispatch (Ristroph, 2016b).

High level of sharing reported by firefighters affirms the cultural importance of food sharing in Native Alaska communities (Kofinas et al., 2016).The importance of subsistence and social connectedness of Rural Alaska communities gives firefighters the confidence to pursue firefighting, knowing their community's food security will not decrease due to their absence (Baggio et al., 2016; Kofinas et al., 2016; Magdanz et al., 2011). The social connectedness and importance of sharing networks is also evident by the reliance on others by all surveyed firefighters regardless of their positions as primarily providers or recipients of subsistence foods.

3.4.2 Future Lengthening Fire Season: Increasing Income Decreasing Time

The increasing length of the fire season as reported and forecasted by both Wotton and Flannigan (1993) and Stocks et al. (1998), creates a challenge for Rural Alaska mixed subsistence-cash economies through the division of time devoted to subsistence and the need to generate cash income. This pathway of the ecological system impacting the social system is show in Figure 5. The increasing length of the fire season can generate additional income for firefighters that is necessary for subsistence (Kofinas et al., 2016). This additional income can fund increases in subsistence food production through the purchase of fuel or subsistence capital such as rifles. Income can also be used to lower the cost of production of future subsistence food production through the purchase of more efficient capital – fuel-efficient four-wheelers for example. It should be noted that some rural Type II fire crews or individual firefighters currently accept fall dispatches to the Lower-48.

Additional time spent fighting fires, particularly in the fall, creates a new conflict by potentially taking time away from subsistence hunting, which has strictly set policies regarding the beginning and end dates of the hunting season (Alaska Administrative Code, 2000). And, whereas fishing is a harvest activity shared by the household or community, hunting is reliant upon a small number of hunters (Sobelman, 1985). Respondents indicated that 95% of rural firefighters are part of these hunting groups. The need to participate in a hunting group conflicts with the need to accept firefighting dispatches. However, the lack of income earning opportunities drives the need to participate in firefighting to generate income. Furthermore, firefighter recusal has the potential to keep an entire crew from being dispatched. Social connectedness and community reliance may encourage firefighters to accept firefighting when it is not in their individual self-interest but in the best interest of the community (Kofinas et al., 2016).

Despite this conflict, 75% of firefighters foresee that their absence during the hunting season would not result in a decrease in community subsistence food production. On the contrary, firefighters anticipate that community sharing networks, joint food production, and winter hunting would enable their communities to maintain consistent levels of subsistence food production in their absence. Firefighters anticipate other community members stepping in and producing subsistence foods – much as they do by harvesting fish in the summer – in the event of a fire assignment taking them away from the community during the fall hunting season despite proxy hunting restrictions.

Firefighters anticipate that they would be able to engage in seasonal switching – changing their hunting activity to the winter hunting season instead of fall – if it became impossible for them to hunt during the fall season. Hunting during the winter season comes with increased risks to hunters, but firefighters did not view the increased risk as high enough to make winter hunting untenable. Additional research on the productivity of winter hunting is needed to understand the capacity of the winter season to make up for reductions in fall hunting.

Hunters would have to completely switch hunting seasons rather than simply hunting when they return from a firefighting assignment as federal and state lands have strict beginning and end dates to the harvest season. Hunting outside of these dates is illegal and can result in monetary fines, revocation of hunting rights, confiscation of hunting equipment, and more (Ristroph, 2016b). The consequences of hunting out of season could be devastating for a community if one of the hunters caught is from a "super household", considering that these households can provide between 60 and 80% of a community's food (Kofinas et al., 2016; Wolfe et al., 2009).

3.4.3 Solutions to a Lengthening Fire Season

A local solution could include communities, villages, or tribes requesting a permit for a community hunt through the State of Alaska Board of Game as described in 5 AAC 92.072. (Fig. 5) While this would not change the dates of the harvest season, it could allow non-firefighting hunters to take more subsistence resources for non-hunting community members than would be allowed under regular “proxy” hunting regulations – “proxy” hunting is when one hunter hunts in place of another hunter (Alaska Administrative Code, 2000).

One potential state and federal level solution would be to increase the length of the harvest seasons. Another solution would be to change from strict season limits to annual community bag limits or quotas similar to what is used in some commercial fisheries and whaling communities (Ristroph, 2016b). Either change would allow communities to participate in subsistence hunting at a time that is both convenient and safe, and would accommodate changes in the fire season, allowing firefighters to continue earing seasonal wages as long as possible. Additionally, such policy changes would also accommodate alterations in animal migration patterns and adaptations to changes in the boreal region at large due to climate change including those that have not yet occurred. This would increase communities’ capacity to adapt to a changing environment, thus aligning the challenge and solution to the same scale of response (Chapin et al., 2010; Chapin et al., 2009; Robards & Alessa, 2003).

Twenty-five percent of interviewees echoed the policy suggestions of lengthened hunting seasons, and/or instituting community bag limits.

3.4.4 Challenges of Low Dispatch Rates for Crews on Rotation List

Many factors affect a Type Two crew’s dispatch and thus, the crew’s wages from wildland firefighting. During interviews, several interviewees mentioned struggling with low dispatch rates. On average, rural Alaska crews – for whom firefighting wages are a vital part of their economy – were dispatched less than once per year from 1986 to 2015 according to dispatch data (Branson, 2016). Type II crews closer to the wildland-urban-interface were dispatched 17 times more than those outside this interface during the 1986 to 2015 time period. A lack of dispatches strains firefighters' ability to balance subsistence and firefighting in the present by limiting income available for subsistence.

One contributing factor to the lack of dispatches for rural Alaska crews from the crew rotation list is the allowance of regions' fire zones to utilize the "closest available resources" (Alaska Wildland Fire Coordinating Group, 2016). The Type Two Crew Management Guide allows fire areas, regions, or forests to utilize the closest available resources as needed until "the fire situation stabilizes or moves into the extended attach phase, or crews hired initially have cycled through an assignment" (Alaska Wildland Fire Coordinating Group, 2016).

To increase dispatch rates for rural crews on the rotation list, limits would need to be placed on the invocation of the "closest available resources" rule. These limits could include strict guidelines on the maximum number of days a fire can burn or the maximum number of acres burned before crews from the rotation list must be used (Alaska Fire Service, 2015). This solution creates a tertiary problem of increasing constraints on Fire Management Organizations trying to protect life and property from damaging wildfires. Beyond a general desire for increased firefighting opportunities, no interviewees reported any policy recommendations regarding firefighting policy.

The increasing number of fires expected in the boreal region due to climate change could resolve the issue of low dispatch rates on its own (Fleming & Candau, 1998; Gillett, Weaver, Zwiers, & Flannigan, 2004; Kasischke & Turetsky, 2006). In that case, the limiting factor for dispatch rates of rual Type II crews would be the availability of crew bosses. To address this secondary issue the Alaska Fire Service would need to expand the trainings they offer to both odd and even numbered years – currently crew boss training is offered on odd numbered years only (Alaska Fire Service). The Alaska Fire Service could also alter the crew rotation schedule to prioritize call outs to crews with new crew bosses. This new rotation list would enable rapid acquisition of skills for new crew bosses – crew boss trainees typically require three assignments in order to gain the experience needed to become a fully qualified crew boss (Alaska Fire Service). This, however, would create a secondary problem of altering the crew rotation schedule, which is already controversial (Trainor, 2006).

A regional solution could be found in the creation of a second rotation list for crew boss trainees within regional fire zones. This rotation list would give crew boss trainees additional opportunities to acquire experience and complete “task books”. Regional fire zones could make crews that were one person less than the required number (17 crew members for in state and 19 for out of state) with the one open seat designated for crew boss trainees. Crew boss trainees on the list would be called until one was found who was available. An alternative to creating understaffed crews would be to send crew boss trainees from the list to fires as an extra member on the crew provided there is room in the transport vehicle. The creation of a second rotation list would likely create similar tertiary problems and controversies similar to that of the crew rotation list.

Crew bosses from other communities and cultures could create cultural tensions within crews. One way to manage these potential conflicts would be to engage with communities prior to the start of the implementation of a crew boss rotation list and get community buy-in of the new rotation list and crew agreement to work amicably with rotational crew bosses.

3.4.5 Opportunities for Additional Research

Changes to firefighter households’ ability to produce subsistence foods would impact subsistence food production for the entire community. Understanding the relationship between Type II firefighters and super households would greatly increase the depth of knowledge regarding impacts to community wide subsistence food production of climate change altered boreal wildfire regimes. Additional research regarding the position of Type II firefighters within their household’s and community’s subsistence food production network provides a valuable avenue for future research.

Conclusion

3.5 Making it Work

Interview and survey data are seemly at odds. Firefighters participating in interviews generally anticipate total subsistence harvest levels to remain constant in a future scenario in which they are absent from their communities during the fall hunting season due to lengthening fire seasons. Yet, firefighters responding to survey questions indicate that a longer fire season would make it more difficult to meet their subsistence needs and the level of conflict between subsistence harvest and firefighting would increase. These differing finding stem from the different questions. Harvest levels can be maintained despite increased difficulty and this is exactly what firefighters stated.

An often repeated statement by interviewed firefighters was, “We will make it work. We always do.” This statement offers some reconciliation of these seeming incongruities. It would appear that firefighters surveyed and interviewed acknowledge that the lengthening fire season will make meeting subsistence needs more hunting more difficult, but that they are willing to accept that increased difficulty in order to continue meeting their communities’ subsistence needs.

3.5.1 System-Wide Challenges

Regardless of potential new policies being implemented, the mixed subsistence-cash systems of Rural Alaska are being transformed. Climate change is altering how these communities relate to the regions they have called home for millennia. (Chapin et al., 2008; Nelson et al., 2008). They are vulnerable to the impacts of climate change, due to their reliance on the natural environment for subsistence (Trainor et al., 2009).

Complex interactions and feedbacks within and between the social ecological systems create situations in which solutions to one challenge often result in the creation of new problems (Chapin et al., 2008). Several suggested policy changes at different levels of the social system could be used to proactively alter the trajectory of changes to the ecosystem. However, there may be unforeseen tertiary social-ecological challenges that, once discovered, would have to be addressed.

Planned transformation of the system cannot ensure the continued subsistence productivity at the community level or necessarily enhance firefighting employment opportunities for Rural Alaska mixed subsistence-cash communities statewide. However, the firefighters interviewed and surveyed here already have a number of coping mechanisms in place for adapting to subsistence-firefighting conflict. While the climate change will continue to impact the boreal system on many levels, communities will continue utilize sharing and cooperation to adapt and maintain subsistence.

Chapter 4: Econometric Models

Abstract

This chapter aims to understand the independent variables impacting wages earned from Type 2 wildland firefighting, hand crews, and the number of dispatches for Type 2 crews. Wages earned from firefighting and number of dispatches are affected by many variables such as fire activity, road connectedness and out of state fire activity. In this chapter, two econometric models are developed that shine light on the impact of these various models on Type 2 community wages and crew dispatches.

Introduction

4.1 Economics of Firefighting and Subsistence

4.1.1 Income and Subsistence

This chapter aims to understand the independent variables impacting wages earned from Type 2 wildland firefighting and the number of dispatches for Type 2 crews. The relationship between cash income and subsistence is complicated (Chapin III et al., 2008). Additional income can aid in participation in subsistence activities by providing the cash necessary to purchase vehicles and gasoline for transportation to and from subsistence harvest areas, ammunition, gear and equipment for hunting, and equipment necessary for preservation of subsistence foods, and more (Berman, 1998). However, participating in income generating employment decreases the amount of time available for participation in subsistence activities and can increase reliance on high priced market foods (Brinkman et al., 2014).

Many Rural Alaska communities report rates of food insecurity at more than twice the national levels, and listed among the reasons for low subsistence resource use are “working/no time” and “equipment/fuel expense” (Holden et al., 2012). The effect of income levels on subsistence is not strictly linear. At low levels of income, subsistence harvest levels are low and households receive gifts of food from other community members (Berman, 1998). As incomes rise, household subsistence harvest levels increase and households become givers of subsistence foods (Berman, 1998). However, as income levels continue to rise, subsistence harvest levels decline due to a lack of time available to participate in subsistence practices (Berman 1998). As incomes rise, market foods can replace the nutritional need for subsistence food, but the risks of losing cultural values associated with subsistence remain.

4.1.2 Forest Firefighting as a Source of Income

Forest firefighting is an important income generating opportunity because it is one of few employment opportunities available in Rural Alaska, where unemployment rates can be upwards of 50 percent (Chapin et al., 2003). It is particularly important as a source of employment for young, entry-level workers (Trainor, 2006). It generates relatively high levels of income – roughly $18.50 per hour per crew member on average in 2015 – which is particularly important in cash-strapped Rural Alaska (Branson, 2016). Wildland firefighting is only currently available during a few months out of the year, and thus minimally restricts the amount of time available to participate in subsistence activities (Chapin III et al., 2008). In 2005, 50% of emergency firefighters surveyed from non-roaded communities reported forest firefighting as their only source of income (Trainor, 2006). In line with those findings, one third of survey respondents – 10 firefighters – stated that firefighting comprised more than half of their household income. (See Chapter 3 for discussion of survey methodology.) Further confirming the importance of firefighting as an income earning opportunity, more than half, 60%, of rural Alaska firefighters surveyed said that they would always accept firefighting assignments. As other sources of income, such as commercial fishing or construction, become less reliable due to fishing closures and reduced State of Alaska capital spending on infrastructure, income from forest firefighting becomes increasingly more important (Trainor, 2006).

4.1.3 Increasing Opportunities for Forest Firefighting

Changes to the forest firefighting-subsistence system are inevitable, as climate change will impact slow and fast system variables (Abatzoglou & Kolden, 2011). Examples of changing variables include an increase in acres burned – 8 million more acres burned in the 2000s than in any other decade, 40% longer fire season, and more intense fire years (Flannigan & Van Wagner, 1991; Sanford, 2015; Wotton & Flannigan, 1993). The forest fire season in Alaska and elsewhere in the Western U.S. is being altered by climate change (Westerling, Hidalgo, Cayan, & Swetnam, 2006). Spring melt comes sooner in the year, resulting in an earlier drying of forest biomass and earlier forest fires. At the same time, the fall rains and cooler weather that fire management organizations rely on to assist in quelling burning fires and decreasing the risk of ignition now come later in the year (Miller, Skinner, Safford, Knappand Ramirez, 2012). As a result, on average, forest fires are beginning earlier in the season, burning more consistently throughout the summer season, and lasting later into the fall season (Kasischke et al., 2010). As the fire season extends further into the fall, the fire season will overlap with the fall subsistence hunting season. The extension in the fire season in Alaska will require more firefighters to participate in firefighting later into the fall, compared to current participation in late-season firefighting. These increases have already been documented across the North American Boreal Region (E. S. Kasischke & Turetsky, 2006).

This increase in the time devoted to forest firefighting is potentially problematic because it decreases the amount of time available for forest firefighters to participate in subsistence activities. A reduction in participation by forest firefighters in fall subsistence hunting could decrease overall subsistence participation and success, at the household or community level. This could also result in prey switching – such as increased participation in subsistence fishing – in order to harvest species available during firefighting's off-season (Berman, 1998; Hansen et al., 2013). It is possible that subsistence harvest increases, due to the increased income from additional forest firefighting income being put towards capital used in subsistence hunting (Berman, 1998). However, the risks to community wide food security from a longer fire season warrant research into potential outcomes and strategies for increasing food security.

4.1.4 "Super-households" and Forest Firefighting

Research by Wolfe et al. (2009), and then again by Kofinas et al. (2016), have indicated that a relative minority of households in Rural Alaska harvest the majority of subsistence resources within the community. This observation is referred to as the "30-70" rule, or "super-household" (Wolfe et al., 2009). These high producing households are important to the community as they contribute to the sharing of subsistence resources to lower producing households (Kofinas et al., 2016).

However, increased participation in forest firefighting by other members of a "super-household," of which there are usually several members and a steady source of income, may increase overall community subsistence harvest by increasing income and capital available to the "super-household," which can increase hunter productivity in current and future seasons (Kofinas et al., 2016; Sobelman, 1985). Historically, it has been common for households participating in subsistence to have at least one working household member finance other household members' participation in subsistence practices (Kleinfeld, Kruse, & Travis, 1981). Participation in forest firefighting by members of non-"super-households" may have a similar effect on total community subsistence hunting by increasing income and capital available for use by other community members who have time available for subsistence. This community sharing of income and capital is common in Rural Alaska communities (Kofinas et al., 2016; Sobelman, 1985). On the other hand, increased income along with increased opportunity cost of subsistence, could result in additional purchases of convenience and market foods.

4.1.5 Firefighting and Subsistence

To date, the majority of research on the impacts of forest fires on subsistence has investigated the ecological impact of fires on subsistence resources, rather than the economic impact of fighting forest fires on subsistence harvest participation and harvest levels.

As rural communities cope and adapt to the extended forest firefighting season, decisions about whether to participate in forest firefighting or subsistence will have major impacts subsistence food production and food security. On average, across rural Alaska, 180% of the USDA's recommended daily protein intake is provided for by subsistence (Fall, 2014). At the community and household level, decisions about firefighting and subsistence will be made against a backdrop of food security. Understanding the trade-offs and decision making processes regarding time use and associated preferences can help stakeholders navigate the impending system transformation for a positive and more secure future.

It is important to remember that subsistence food production and firefighting are not mutually exclusive; it is not an either/or situation. The two activities have historically been complements according to interviews and surveys conducted herein. The primary query of this chapter is to further understand the relationship between these two activities and model how subsistence and market food production might be impacted by changes in firefighting opportunities due to climate change. Although these two activities have historically been complements, this research aims to answer the question of whether there is a point at which they become substitutes.

4.1.6 Understanding Crew Dispatch and Fire Management

Fire crews are required to consist of at least 18 crew members to be dispatched including at least one crew boss present (Alaska Wildland Fire Coordinating Group, 2016). For out of state dispatches, the crew must be at least 20 crew members in size including one crew boss (Alaska Wildland Fire Coordinating Group, 2016). Type 2 crews are dispatched via a crew list which determines the order of dispatch. The crew at the top of the list is dispatched first, if they refuse the dispatch, they are moved to the bottom of the list and will not be recalled until the reach the top of the list. After they accept the dispatch and are dispatched more than three consecutive 8 hour periods, they are moved to the bottom of the list. Once a crew has moved to the bottom of the list, the next crew on the list is moved up to the primary slot and will be the next crew called. If a crew cannot meet the crew size requirements, they are not placed on the list. Crews maintain their position on the list during the off-season; any dissolved crews removed and any new crews added to the bottom of the list (Alaska Wildland Fire Coordinating Group, 2016). For example, if a crew finished the fire season at the top of the rotation list – next in line for a fire call – they would begin the next season as the first crew to be called out. If a crew is the last to go on a fire call in year one, then they begin year two at the bottom of the crew rotation list.

Crews can be dispatched within their fire zone – the state is broken up into fire zones each with its own fire management plan and fire manager – at the request of the fire manager with only 16 crew members including a crew boss without losing their spot on the crew rotation list.

Non-Type 2 resources, such as engine crews and Type I resources such as hot shot crews, act as initial attack crews. These are the crews that will be immediately dispatched to suppress a fire. Engine crews are crews that are on the road system and are associated with a fire engine (Alaska Wildland Fire Coordinating Group, 2010). Hot shot crews are highly skilled fire crews dispatched to fires on and off the road system (Alaska Wildland Fire Coordinating Group, 2010). Helitack crews, are fire crews that are dispatched via helicopter to fires for initial attack purposes. Type 2 hand crews typically are dispatched later in the life of a fire to ensure complete suppression. Overlap and substitution exist in the work done by these different types of firefighting resources depending on proximity to the fire and availability of other resources (Kohley, 2017).

Fire Management Organizations divide lands within the state of Alaska into categories that determine how fires on those lands will be fought. Lands are divided into critical, full, limited and modified suppression options (Alaska Wildland Fire Coordinating Group, 2010). Critical lands are lands have the highest priority for fire suppression and are lands on which all fires will be immediately suppressed. Critical lands typically surround homes and communities and fires on these lands represent an imitate threat to life and property (Alaska Wildland Fire Coordinating Group, 2010). Full suppression lands are the second highest priority for fire suppression and generally include protection for valuable uninhabited structures where there is no threat to human life. The limited management option is used for large landscapes where fires are routinely allowed to burn to function in its ecological role (Alaska Wildland Fire Coordinating Group, 2010). Modified lands are lands that change protection status after a set conversion date. Prior to the conversion date, modified lands are managed in the same manner as full protection status lands. After the conversion date, fires are suppressed as they would be on limited lands where fires are typically allowed to burn. Conversion dates are reviewed annually and depending on the landscape in question can either occur on July 10, August 10, August 30, or September 30 (Alaska Wildland Fire Coordinating Group, 2010). The transition from limited to full land management status indicates decreased fire danger after the conversion date (Alaska Wildland Fire Coordinating Group, 2010)

4.2 Econometric Models and the Relationship Between Firefighting and Subsistence

4.2.1 Simulating a Small, Rural Economy

Modeling is frequently used as a tool for understanding economies of any size (de la Montaña, Moreno-Sánchez, Maldonado, & Griffith, 2015; Marcuss & Kane, 2007; McCulla & Smith, 2015). Economic modeling has been used as a tool to understand the mixed cash-subsistence economies like that of Rural Alaska for decades (Berman, 1998; Brander & Taylor, 1998). Modeling allows researchers to understand the impact of unobservable economic factors and evaluate the sensitivity of various aspects of the economy to changes in other economic variables. For example, in the case of Easter

Island, economic modeling allowed Brander and Taylor to create and test a hypothesis about the historical causes that led to the decline of the island hundreds of years prior to their modeling (Brander & Taylor, 1998). Modeling can provide valuable insight into economies that could only otherwise be ascertained through intense survey, if at all.

For wildland firefighting specifically, modeling has been used to understand the most efficient way to utilize various types of firefighters. For example, Donovan (2006) generates a deterministic balanced transportation model, which was used to determine the effects of various annual wildland fire attributes on the use of contract crews (Donovan, 2006). Through this modeling, Donovan was able to determine that the peak number of fires in a given year was the major determining factor influencing the number of contract crews hired (Donovan, 2006).

For this paper, several models were used to understand Rural Alaska economies and how they would respond to a changing future. Two econometric models were used to determine the effect of increased acres burned on firefighting crews and communities. The first model estimates the relationship between Rural Alaska community firefighting wages and annual acres burned. The second model estimates the relationship between Rural Alaska crew dispatches and acres burned.

Methods

4.3 Econometric Models

4.3.1 Econometric Model Inputs

Several variables were included when modeling the changes in rural Alaska firefighting such as firefighting wages, firefighting dispatches, acres burned on differently managed lands, presence or absence of road, rural or urban nature of the community, number of fires burning simultaneously, and acres burned by geographic zone. Not all of the above variables were found to have a significant impact on rural community firefighting wages or crew dispatch levels.

Historic wildland firefighting wage and dispatch data were acquired from the Alaska Department of Natural Resources. This data includes annual, total wages by community of residence, and annual in-state and out-of-state dispatches by community of fire crew. Wages were occasionally reported for communities without fire crews when a crew member (or members) commuted from a nearby community to a community that had a fire crew. Wages reported for communities without fire crews were attributed to the geographically closest community with a fire crew. These data are reported annually for the years 1986-2015.At a community level, these wages ranged from $0 to $523,000 for rural Alaska communities in 2015 (Branson, 2016). Urban communities were defined as boroughs with populations over 55,000. All other communities were considered to be rural, and were further separated into roaded – communities with roads connecting them to main highways—and non-roaded – communities without road connection.

Annual acres burned were provided by Alaska Fire Science and include data for acres burned by fire management option area from 1986-2015. Acres burned for the United States were retrieved from the US Forest Service for the same years.

4.4 Modeling Wages

4.4.1 Changing Wage Levels

Wages are modeled to better understand what variables impact a community wages from firefighting. Whether or not communities earn more from Type 2 firefighting in seasons with high numbers of acres burned in Alaska, high numbers of acres burned within their community's geographic zone, or in years when the Lower 48 has a high number of acres burned is unknown. Even the impact of a community's proximity to roads on their firefighting wages is unknown. This model aims determine the major factors that affect community firefighting wages.

4.4.2 Using Tobit to Model Wages

A Tobit model was used to estimate the effect of Alaskan acres burned on community wages from firefighting. The Tobit model is well suited for modeling community wages from firefighting because for many of the communities there are a significant number of years for which their wages from firefighting are equal to zero (Wooldridge, 2012). (See Appendix D.) When the value of wages is non-zero, the values are roughly continuously distributed and exclusively positive which further fits the Tobit distribution (Wooldridge, 2012). This model takes on the general form of Equation 1:

(1) $W = f(AKacres, u, r, L48)$

Where W equals community wages, f equals the Tobit function, and the variables are: Alaskan acres burned on critical, full and modified lands ($AKacres$); urban location (u), road connectedness (r), and Lower-48 acres burned ($L48$).

4.5 Modeling Dispatches

4.5.1 A Two Stage Model

Total dispatches were modeled in order to understand the impact of several firefighting related variables on the number of times crews are dispatched and therefore unavailable for subsistence food production. A two-stage model was used to look at the likelihood of being dispatched at least once in a year, and then the factors influencing level of dispatch, given that dispatches are greater than zero (Wooldridge, 2012).

The negative binomial model was chosen because of the fact that it uses the Poisson distribution, which fit the dispatch data; however, the data were overdispersed, meaning the distribution of the data extended far to the right tail creating greater variability in the dataset than would be expected based on a normal distribution (Wooldridge, 2012). Because the negative binomial model is more accommodating to overdispersion than the Poisson model, it was chosen as the model for dispatch data at the crew and community levels (Wooldridge, 2012). The model takes the general form of Equation 2 below.

(2) $D = f_i(AKacres, WUS, u, r), f_j(AKacres, WUS, u, r)$

Where D equals dispatches, f_i equals the binomial model, and f_j equals the zero inflated model. $AKacres$ equals Alaskan acres burned on critical full and modified lands by fire management zone, WUS equals Wester US acres burned (not including Alaska), u equals the urban indicator variable, and r equals the road connectedness indicator variable.

4.5.2 Appropriateness of Model and Variables

Model specification began with contemplating the variables that could potentially affect the probability of a community or crew being dispatched – variables such as acres burned in Alaska and the Continental US. From there, this list of variables was expanded to include variables found in the literature of others – variables such as peak number of fires burning simultaneously. All of these variables were then tested in the zero inflated negative binomial model in both the first stage – logit model – and second stage – negative binomial model. The final list of variables that were kept in the model are: annual sum of acres burned on lands designated to critical, full or moderate suppression options by zone, annual sum of acres burned in the Western United States, an indicator variable indicating whether a community is road-connected, and lastly, an indicator variable indicating whether the community was considered urban. (See Appendix E for full model results.) Rejected variables include a variable representing the number of days fires burned by Alaskan fire zone, severity of the fire year, Lower-48 acres burned and the total number of Type 2 fire crews per community. The number of days fires burned was found to not be significant at the 90% confidence level and the number of Type 2 crews per community was too highly correlated with urban and road connectedness indicator variables. For modeling dispatches, Lower-48 acres burned was found not to be significant at the 90% confidence interval, however Western US acres burned were found to be significant at this level.

The model underwent many specifications that differed by the sets of variables that were included. These various iterations were compared to determine which explained the most statistical variation. Variables were removed based on the strength of their logical connection to explain variation in the dependent variable and their statistical significance. For example, the log of acres burned was kept through iterations, despite initial lack of statistical significance due to its logical connection to dispatches. The relationship between the number of Alaskan acres burned and dispatches was needed for calculating expected future dispatches in reference to climate change, which is expected to impact acres burned. Meanwhile, an interaction term of the road-connected indicator variable and community population was quickly dismissed when found to be statistically insignificant and lacking in clear logical justification for inclusion.

4.6 Utilizing a Logit model

4.6.1 The Logit as a First Stage Model

The first-stage model was a logit model. This model generates the probability of a community having non-zero dispatches given a set of independent variables (Wooldridge, 2012). The logit model was specifically selected due to the annual dispatch by community dataset containing an excessive number of zeros (Wooldridge, 2012).

4.7 Negative Binomial Model for Modeling Dispatches

4.7.1 Justification for Using Negative Binomial

The negative binomial model was used to understand the variables impacting the number of times a crew gets dispatched, provided they get dispatched at least once (Wooldridge, 2012). This model type was used due to the distribution of the crew dispatches. The zero inflated negative binomial model uses a Poisson distribution which accommodates the high number of zeros, and truncation at zero (meaning crews cannot have negative dispatches) present in the crew dispatch data (Wooldridge, 2012). (See Appendix E.)

Results

4.8 Individual Model Results

4.8.1 Wage Model Results

A total of four variables were estimated to have the most significant impact on community firefighting wages: Alaskan acres burned on critical, full and modified lands; urban location, road connectedness, and Lower-48 acres burned.

Alaskan acres burned on critical, full and modified lands are the sum of acres burned on critical, full and modified lands within a given fire zone. Urban location is an indicator variable equal to 1 if the community is urban (Anchorage, Matanuska-Susitna Borough, Fairbanks North Star Borough, and Kenia Peninsula Borough) and 0 if the community is not urban. Road connectedness is another indicator variable equaling 1 if a community is connected to a road and zero if it is not. Lastly, Lower-48 acres burned is the sum of all acres burned in the Lower-48. All urban communities are road connected, but avoid multicollinearity they were only included in the urban variable and not in the road-connected variable.

The three most influential variables were urban location, road connected location and acres burned in the Lower-48. The first two variables while seemingly related, each communicate something different. Being in an urban community also increases your chances of having non-zero wages by five times that of a rural community between 1986 and 2015. Most urban areas have more than one crew, but there are several rural communities that also have more than one crew. Urban areas have an increased number of human-caused fires and are surrounded by critical lands which are suppressed immediately. Meaning there are more fires fought around urban communities.

A community's location along the road system was another variable with a large coefficient. For this analysis only non-urban, road connected communities were included in this variable. Communities along the road system have increased access to lands where human-caused fires are more likely to occur. Communities connected to a road system– which includes some rural communities such as Tok – are more frequently dispatched than rural crews. This correlates with an increase in fires burning in that area, and the fact that those fires are burning on lands designated to critical or full suppression management options, meaning each fire is fought. Communities and their crews in the WUI area are, by definition, on the road system, so they also have the ability to get to fires quickly. Because of this, they are likely preferentially dispatched more frequently within their zones than crews outside the WUI, either within or outside the zone. This increase in dispatches results in a 1.7 times higher chance of having non-zero wages compared to communities not located along the road system.

Acres burned in Alaska and in the Lower-48 have a positive impact on wages. The Lower-48 annual acres burned increased wages earned from firefighting by 18% for every 10% increase in acres burned, whereas Alaskan annual acres burned has a much smaller impact on wages – increasing wages by 1.4% for every 10% increase in acres burned on Alaskan wildlands. (See Appendix D for full model results.)

Alaskan acres burned on critical, full, and modified management option lands were initially tested separately. Critical and full management option land had a very positive impact on wages, while modified lands had barely any impact on wages earned. None of these variables alone were significant at the 90 percent confidence interval. The lack of significance can partially be attributed to the fire database, which only includes fires over 100 acres. This 100 acre cutoff for inclusion into the database results in an underrepresentation of fires on critical lands due to the fact that fires on those lands rarely achieve sizes as large as 100 acres. These fires are fought immediately and intensely because they pose an immediate threat to life or property. The same problem of under representation is likely at play on acreage designated to the full management option because fires on those lands are rarely allowed to reach 100 acres (Kohley, 2017). Lands designated to the modified management option, however, are fought on a "wait and see" basis for approximately the first half of the fire season and then converted to full suppression later in the fire season. Due to this fire policy, fires on these lands can consume a large number of acres before a crew is ever dispatched to fight that fire. So, logically, the relationship between acres burned on these lands and wages earned is far from perfectly correlated. Due to the lack of significance of acres burned individually on these lands, the sum of acres burned on these lands was eventually tested and found to be a significant independent variable for estimating community wages as stated above.

As previously stated, a 10% increase in acres burned in the Lower-48 results in an 18% increase in expected wages. Alaskan Type 2 fire crews are dispatched for longer time periods to the Lower-48 than they are typically on Alaskan fires (Kohley, 2017). Alaskan Type 2 crews are only dispatched to the Lower-48 after all local resources have been exhausted; meaning that there is a threshold below which no Alaskan crews will be dispatched to the Lower-48. That threshold was not observed during the time period studied – 1986-2015. While not all fires in the Lower-48 are fought immediately, many more of them will be promptly fought with all available resources, compared to those in Alaska, where many fires burn in areas that do not threaten life or property. The wildland-urban-interface in the Lower-48 includes acreage orders of magnitude larger than those in Alaska (Radeloff et al., 2005). Many more lives and much more property is at risk in California fires, for example, than in a fire in the middle of the Yukon-Koyukuk Census Area (Radeloff et al., 2005).

4.8.2 Logit Model Results

Three variables were found to be highly impactful and significant at the 90% confidence level to the likelihood of a crew getting dispatched. Those variables were: whether or not the community was urban; annual number of acres burned by zone on lands designated to critical, full or modified management option lands; and acres burned in the Western U.S.

Urban crews were found to be 8.1 times more likely to *not* be dispatched, compared to non-urban crews. While urban crews have more people and property in need of protection from wildfires, they also face more competition for fire suppression from non-Type 2 firefighting resources, such as engine crews and hotshot crew, which tend to be located in urban areas. While nearly every area of the state has non-Type 2 firefighting resources, the vast majority are located in urban areas such as Fairbanks, Anchorage, and the Matanuska-Susitna Valley (Branson, 2015). All urban communities are road connected, but avoid multicollinearity– they were only included in the urban variable and not in the road-connected variable. According to Adam Kohley (2016), a 20 year incident commander for the Alaska Fire Service, fires in urban areas are typically suppressed by non-Type 2 crews because those fires require rapid suppression and will be kept to very small sizes, ideally. Type 2 crews are not equipped – either with the tools or training – to rapidly suppress fires or be perform the initial attack on a fire (Kohley, 2017). Type 2 crews are much more adept to “mopping up” fires (ensuring complete suppression on fires that are nearly out) (Kohley, 2017). On small, urban fires, dispatching Type 2 crews is often deemed unnecessary as non-Type 2 resources can easily “mop up” these small fires (Kohley, 2017).

Increasing numbers of acres burned in the Western U.S. increases an Alaskan crew’s likelihood of being dispatched at least once. A 10% increase in acres burned in the Western U.S. increases likelihood of dispatch by 37%. When the fire season in the Lower-48 overwhelms local firefighting capacity, Alaskan Type 2 crews have the option of being dispatched to the Lower-48 (Branson, 2016; Kohley, 2017). While some Type 2 crews choose not to fight Lower-48 fires due to the different ecology and fire conditions, many do (Branson, 2016; Nikolai, 2017). When Lower-48 acres burned are high, the Lower-48 needs as many Alaskan firefighters as possible, so they will take as many crews as is attainable (Kohley, 2017).

One additional variable was found to be significant at the 90% confidence level - whether the community was on the road system. Being on the road system made a crew 1.9 times *less* likely to be dispatched compared to crews off the road system. Crews on the road system, like urban crews, are more likely to face competition from non-Type 2 firefighting resources (Branson, 2015; Kohley, 2017). While the vast majority of initial attack resources are located in urban areas, roaded areas have more non-Type 2 firefighting resources than non-roaded areas (Branson, 2015).

4.8.3 Results of the Negative Binomial Model

Acres of wildland burned in both Alaska and the Western United States were statistically significant at the 90% confidence level on predicting the number of times a crew was dispatched. Road connection and urbanity were also highly significant. Model results indicate that a 10% increase in the sum of Alaskan acres burned on critical, full, and modified protection option lands by fire zone increases a crew's expected dispatches by 10.3%. Utilizing the sum of acres burned in these three management types takes into account the flammability of a crew's surrounding geography and the increase in acres burned around urban and road connected crews' zones. Those crews will have increased dispatches that correspond to the increased acreage burned in those areas. Because acres burned in the fire zone of the crew were used, the policy of utilizing "closest available resources" is also accounted for. In total, regardless of geography, in particularly bad fire years that generate significantly more acreage burned around the state, crews will experience notably more dispatches.

Acreage burned in the Western US also impacts dispatches in Alaska when Alaskan crews are dispatched to the Lower 48, but unlike acres burned in Alaska, they have a negative impact. For a 10% increase in acres burned in the Western United States, average crew dispatches is expected to decrease by 3%. This apparent contradiction is the result of longer dispatches (Kohley, 2017). When a crew is dispatched to the Lower-48, they are typically out of the state for two-weeks, according to fire management officers and Type-2 crew members (Kohley, 2017). These longer dispatches lower the number of times a crew can be dispatched. Dispatches in Alaska can, and typically do, have shorter turnarounds (Kohley, 2017). For example, a crew can be on a fire for as few as three, eight-hour shifts before being returned home and sent to the bottom of the crew rotation list (Alaska Wildland Fire Coordinating Group, 2016). In addition, interviewees indicated that some crews intentionally refuse dispatches to the Lower-48, citing difficulty in acclimating and lack of familiarity with different ecology and fire conditions, making firefighting more difficult and less safe for their crewmembers.

Area burned is not the only determinant of dispatches for a crew. If an urban crew is dispatched at least once they are estimated to receive 1.7 times more dispatches than rural crews. The lands around them contain more wildland-urban interface (WUI) and more critical and full protection status lands (Kohley, 2017; USDI, 2017). Also, humans generate a higher number of fires compared to natural causes, so larger population centers will experience more fires (AICC, 2017a). In contrast to urban crews, rural communities have smaller populations and a smaller footprint. This results in fewer fires fought near rural communities (AICC, 2017b; USDI, 2017). Fire management officers are permitted to use the "closest available resources" when fighting fires (Alaska Wildland Fire Coordinating Group, 2016). With the larger number of fires on critical and full management option lands near urban communities, urban crews can benefit from the use of the "closest available resource" rule without having to rely on being at the top of the crew rotation list in order to be dispatched.

Road connectivity was the fourth significant variable impacting the number of crew dispatches. Crews on the road system are dispatched 1.3 times more often than rural non-roaded crews. Road connected crews have the ability to quickly respond to fires, whereas rural crews have to fly to fire locations increasing the time and cost of utilizing these crews to respond to fires. Large swaths of land along road corridors are included in higher level protection management options as well, giving road connected crews more access to fires that will be fought (Branson, 2015). It is unsurprising given their geographic isolation that rural Alaska communities have a reduced probability of being dispatched compared to road connected crews.

Discussion

4.9 Discussion of Variables and Implications

4.9.1 Omitted variables

The Ramsey test for omitted variables indicated the presence of omitted variables in the wage model. Omitted variables include: number of people per crew, length of dispatch, order on crew rotation list at the beginning of the fire season, and crew distance from fires. Some of these omitted variables are partially captured by variables in the model, while others remain completely omitted due to lack of data. The impact of their omission is discussed below. Omitted variables could result in misspecification of the model and, incorrectly attributing the effect of the omitted variable to one of the variables that was included.

Number of people per crew is relevant for several reasons. Crew size, as previously stated, is a requirement for certain dispatches. Crew size is also important for wage modeling, as a larger crew will earn higher total wages than a smaller crew, all else equal. It is possible that communities with larger populations have a larger firefighting labor pool and therefore larger crews on average. Total community population was tested as an independent variable and found to have an insignificant effect on the likelihood of dispatches, or the number of positive dispatches, and did not improve overall model performance. No data was available during the preparation of this research that explicitly reflected crew size; for these reasons, this variable remains omitted. If crew size were positively related to road connection, it is possible this omission would result in an overstatement of the effect of road connection to wages.

Length of dispatch is a variable that would greatly impact firefighting wages, as Type 2 firefighters are paid by the hour. Furthermore, this can affect time available for subsistence food production. This variable could also impact the number of dispatches. When crews are gone on longer dispatches, it is possible that they would have less time available for future dispatches. However, it is likely crews few dispatches per year, have enough total time remaining to be able to absorb increased dispatch lengths and increased number of dispatches. Unfortunately, data on the length of dispatch or even average length of dispatch per crew per year is unavailable.

A crew's position on the crew rotation list was not included due to lack of data. Crews at or near the top of the rotation list at the beginning of the fire season have a much higher chance of being dispatched than a crew at the bottom of the list. Thus, a crew's order on the rotation list would be a variable that would help explain their dispatches in a given year. According to the Alaska Fire Service, while the current crew rotation list is publically available at all times, historic crew rotation lists are not maintained. No proxy for a crew's position on the rotation list could be found, however, the year-to-year correlation in error terms that this problem generates is taken into account by statistical clustering and paneling on data by community and crew.

Crew distance to fire was identified as a potentially useful explanatory variable due to the "closest available resources" rule (Alaska Wildland Fire Coordinating Group, 2016). As previously mentioned, regional fire managers are able to use crews from within the zone to attack a fire until the fire is under control, or the crews have cycled through their assignment, *before* turning to the crew rotation list. If crews are located close to fires, then, using this rule, they likely have a higher chance of being dispatched – initially and repeatedly. This variable is partially accounted for by the variable of acres burned by zone on lands categorized to critical, full, and modified management options. Assigning acres burned on a zone basis takes into account a crew's rough proximity to fires in a very broad sense, as some zones, such as the Galena Zone, are very large. The explanatory power with regards to community firefighting wages and crew dispatches of the sum-of-acres-burned variable is partially reflective of the explanatory power that could be expected from a measure of distance to fire.

The number and use of non-Type 2 resources in various communities was the last potential omitted variable. In a location with a high number of non-Type 2 resources, such as Fairbanks, these non-Type 2 firefighters might fight a fire from ignition to full-suppression, especially if the fire is small or relatively easy to contain. This competition between Type 2 crews and initial attack crews for fires to fight means that the presence of non-Type 2 crews could have a significant impact on Type 2 firefighters' dispatches and wages. These resources are entirely located within communities that, for this research, were designated as urban. It is possible that by omitting information on non-type 2 resources, the impact of urban location is overstated. While the urban designation was not intended to be a proxy for competition from non-Type 2 resources, it seems to be acting as such. (See results section below.)

4.10 Dispatches and Road Connectivity

4.10.1 Crews Versus Communities

The impact of acres burned in Alaska and the Western U.S states have a similar, previously discussed, effect on communities and crews. Road connection and urban designation had different effects on communities versus crews. Being on the road system or in an urban community decreases a crew's likelihood of having non-zero dispatches. However, when all crew dispatches in an area are summed, the community's likelihood of being dispatched at least once is increased by being on the road system or urban. For a single crew, being on the road system or in an urban area means there are more crews that could potentially be dispatched to a fire. More crews to be dispatched lowers the likelihood of dispatched for any single crew.

Dispatches, both in and out of state, are understandably highly significant to increased wage earning. However, Lower-48 dispatches generate much more income on average per dispatch than dispatches within Alaska. This is likely due to longer duration of dispatch for Lower-48 fires, compared to Alaska fires, where a crew can be dispatched for as little as three 8-hour shifts. For Lower-48 dispatches, crews are also required to have 20 crew members, versus only 16 in-state.

These results indicate that urban communities, on the road system and that are also dispatched to the Lower-48, will earn higher wages in a given year, due to their proximity and easy access to fires that threaten life and property and the longer dispatch length for Lower-48 dispatches. Road connected communities are also more likely to be in close proximity to a higher number of fires because humans cause more fires than lightening in the state of Alaska, and therefore create more opportunities to fight fire.

Rural crews will likely earn less in wages in an average year because they are not as close to the fires that are most frequently fought. They also have logistics working against them, as they are unable to drive to fires. The smaller population in rural communities means that rural crews are also less likely to see the sheer number of human-caused fires that an urban crew would see. Altogether, this results in rural crews more frequently having years with zero earnings from firefighting than urban crews.

Conclusion

4.11 Utilizing the Dispatch and Wage Model to Anticipate the Future

4.11.1 Impact of Dispatch and Wage Model

Comparing the wage and dispatch models paints a more complete picture of the Type 2 firefighting system. Broadly speaking, years with more acres burned in Alaska and the Lower-48 will generate higher wages, as will being on the road system or in an urban location. While Western US acres burned tend to generate fewer dispatches than acres burned in Alaska, these longer dispatches generated more wages. While being on the road system or in an urban location may not get you more positive dispatches, once you finally get dispatched, you're likely to get more dispatches than your rural counterparts, which increases overall wages. This would result in higher average annual firefighting wages for crews located in rural roaded communities than crews located in rural non-roaded communities.

Alaskan acres burned, which when increased is associated with increased dispatches and wages, will be the most helpful for our evaluations of the impact of climate change altered boreal wildfire regimes on Type 2 firefighters. This is also the portion of the model that is most susceptible to Alaska fire management organization policy changes discussed in Chapter 3.

Chapter 5: Food Production Simulation

Abstract

Changes to Type 2 wildland firefighting caused by climate change's impact on the boreal wildfire regime may impact subsistence food harvest. Changes in income and time available to participate in subsistence can cause subsistence harvest levels to change at a household and community level. This chapter uses data from public sources and surveys and interviews conducted herein to develop a food production simulation for Rural Alaska communities. These simulations indicate that communities will be able to continue to produce sufficient amounts of subsistence food except under the most extreme forecasts of increased acreage burned.

Introduction

5.1 Food Simulation Overview

5.1.1 Maximizing Utility to Determine Levels of Food Production

In the food production simulation developed here, food production is modeled in the context of utility maximization. In order to analyze how residents of Rural Alaska demand forest firefighting employment and how that demand impacts subsistence food production, food production was put in the context of utility maximization. Maximization of utility has been used for hundreds of years as a theory to describe the behavior of individuals or groups of individuals in a market place (Eatwell, 1987). The term utility, while having many definitions amongst both economists and philosophers, is used here to connote the summation of a set of goods and activities that bring satisfaction to the individual or group of individuals (Eatwell, 1987). By mathematically maximizing a community's utility – which takes the Cobb-Douglas form meaning it has constant elasticity of substitution between capital and labor – the community's allocation of time between firefighting employment and subsistence harvest can be calculated, given their preference for various goods and services.

In this chapter, output from econometric models, General Circulation Models (GCMs), surveys, and interviews are combined with subsistence and economic data to develop a food production simulation. This simulation attempts to determine future subsistence fall hunting production levels and market food purchase levels given the increase in acres burned as estimated by the GCMs and associated increase in firefighting dispatches and wages. This simulation takes on the basic functional form of a Cobb-Douglas production function, and uses household production function theory to estimate community level utility from food production.

5.2 General Circulation Models

5.2.1 Alaska Climate Model Forecasts for Acres Burned

General circulation models, GCMs are a particular type of climate model that estimates weather patterns given difference representative concentration pathways, RCPs (IPCC, 2013). There is a precedent of utilizing the output of GCMs with the purpose of modeling scenarios associated with boreal wildfire costs. In 2016, Hope et al. used several GCMs to model increased wildfire suppression costs (Hope, McKenney, Pedlar, Stocks, & Gauthier, 2016) Resultant forecasted acreage burned in Alaska of several General Circulation Models (GCMs) were compared to determine several likely possible future scenarios regarding future acres burned by wildfire in Alaska. The models chosen were selected out of a series of climate change models used by Scenarios for Network for Alaska and Arctic Planning for their accuracy in modeling arctic regions (Scenarios Network for Alaska and Arctic Planning, 2017). GCMs can be run at many representative concentration pathways (RCP) options. These various pathways represent assumptions about how much CO_2 is present in the atmosphere under different climate change policy scenarios (IPCC, 2013). For this chapter, RCP 45 was used because this concentration pathway represents a middle-of-the-road climate scenario (IPCC, 2013; Wayne, 2013). RCP 45 assumes no drastic increases or reductions in climate or emissions policy, meaning these model results represent the variation in possible future scenarios arising from a "no change" climate policy (IPCC, 2013; Wayne, 2013).

Methods

5.3 Simulation Inputs

5.3.1 General Circulation Models

The three GCMs chosen here to represent a variety of possible future scenarios were the NASA Goddard Institute for Space Studies model E-Russel, the Institute Pierre-Simon Laplace coupled model - version 5A, and the National Center for Atmospheric Research – Community Earth System model 4 (Scenarios Network for Alaska and Arctic Planning, 2017). These three models were chosen as they represented low, medium and high changes, respectively, in acres burned scenarios, all within the "no change" climate policy representative concentration pathway.

Forecasted acreage burned on lands designated critical, full, and modified lands as of 2016 were summed for each of the GCMs used. Using these GCMs, the high acreage burned scenario is associated with a 47% increase in acres burned on critical, full, and limited management option lands over 100 years. The middle acreage burned scenario is associated with a 15% increase in acres burned on these lands. Lastly, the low acreage burned scenario is associated with a 1% increase in acres burned on these lands.

5.3.2 Simulation Inputs

Prior to modeling Rural Alaska economies, wildland firefighters were surveyed and interviewed about their subsistence, firefighting, preferences and expected behaviors. (See Chapter 3 and Appendices A, B, and C for survey methodology and results.) Survey data was used to parameterize coefficients for preferences and food production productivity and to inform assumptions about future behaviors. Survey data yielded productivity measures for subsistence harvest, preferences for wildland firefighting, and methods of adaptation to increased firefighting opportunities. While this data fills in critical holes in existing data, these point-in-time measurements and single species group focus made it necessary to assume preferences, productivity, and behavior do not change in the future.

Historical subsistence data was acquired from the Alaska Department of Fish and Game. This data included total pounds harvested, by species, by community. The drawbacks of this data source are that they are point-in-time measurements. Repeated surveys are cross sectional in nature and are not repeated in communities on a regular basis. This limits wat can be said about harvest changes over time.

5.3.3 Combining Climate, Wage and Dispatch Models

Utilizing the results of the wage and dispatch scenarios, rural non-roaded communities' wages from firefighting are expected to increase under the low, medium, and high acreage burned scenarios by 1%, 17%, or 54%, respectively. These results are arrived at by multiplying the percent change in acres burned on critical, full, and modified lands by the exponentiated coefficient on the sum of acres burned on these same lands, derived from the previous wage model (Wooldridge, 2012).

Time dispatched on fires away from non-roaded rural communities is expected to increase by 1%, 15%, or 47%. Similarly, these percentages were calculated by multiplying the percent change in acres burned on critical, full, and modified lands by the exponentiated coefficient on the associated variable in the dispatch model derived in the previous section. For wages and dispatches, the assumption was made that the community had positive wages and dispatches, so the likelihood of positive wages and positive dispatches was assumed to be one.

The same process was conducted to calculate increased wages and dispatches for rural roaded communities. One additional step take for roaded communities was to multiply the initial wage and dispatch levels by the coefficient of the roaded indicator variable, derived in the wage and dispatch models, respectively (Wooldridge, 2012). For those rural communities that are on the road system, wages from firefighting are expected to increase by a similar 1%, 17%, or 54% for the low, medium, and high acreage burned scenarios. Time away from communities is expected to increase by 1.5%, 21%, or 66% for the same scenarios, respectively.

5.4 Methodology of Food Production Simulation

5.4.1 Utility

In this application, a Becker-type model is used to determine the demand for forest firefighting labor (Huffman, 2010). This simplified model of household production produces two goods: subsistence foods and market foods (which are purchased, but referred to here as production due to requiring cash and time as inputs), subject to a taste parameter. This simplified utility function which models only two foods takes the form of Equation 3.

(3) $Utility = U(Z_1, Z_2; \tau)$

Where Z_1 is subsistence food production, Z_2 is market food production, and τ denotes the community's taste for these two goods. In this case, community production is treated as household production (Huffman, 2010). Due to the sharing of capital, labor, and goods produced within communities, this treatment of a community as a household for the purposes of determining forest firefighting employment demand is justified (Kofinas et al., 2016). Results of the survey conducted herein confirmed the assumption and the work of Kofinas et. al. (2016) that high rates of capital, labor, and goods sharing occurs in rural Alaska communities.

5.4.2 A Generalized Production Function

To produce subsistence foods, goods, x_1, and time, t_1, are needed. To produce market foods, goods (cash), x_2, and time, t_2, are needed. This production function will have constant returns to scale and will be concave (Eatwell, 1987). The general production function for food is represented below in Equation 4.

(4) $Z_i = G_i(x_i, t_i; \varphi_i)\ i = 1,2$

Where G_i is the function representing the production of food, in which the inputs to production are goods, x_i, and time, t_i. Here, φ_i is the community's technology parameter representing the efficiency of its technology. For example, the efficiency of a new snow machine. While time spent on subsistence production can generate utility even if subsistence food is not produced, this production function does not allow for the coproduction of utility and food production. This is further discussed model limitations.

5.4.3 Time and Income Constraints

The community has time and income constraints. The community cannot spend more than the total time available in a given time period, nor can they spend more than their income in a given time period. These constraints are represented below in Equations 5 and 6.

(5) $T - t_1 - t_2 - h = 0$

(6) $Wh + V - P_1x_1 - P_2x_2 = 0$

T is total time available in the time period, h is the number of hours worked for pay, in this case forest firefighting hours. Total time here is constrained to only the time devoted to non-subsistence household activities or non-firefighting wage earning employment for community residents aged 16-65 between the days of April 1 and September 30. Community hours worked for wildland firefighting were calculated using 2017 surveys from 30 wildland firefighters, Alaska Fire Science crew records, and the 2016 America Time Use Survey. (Parameterization of the simulation is discussed below.) An average of

800 hours per dispatch was calculated and used in the model (Branson, 2016). W is the wage rate for fighting forest fires, V is unearned income, such as the Permanent Fund Dividend, P_1 is the price of goods purchased to produce subsistence, and P_2 is the price of goods purchased to produce market foods.

In order to calculate the demand for forest firefighting labor, the community's utility is maximized. Maximization of utility is a necessary assumption of the household production function. This maximization will determine their optimal consumption of goods and allocation of time. To do this, the time and income constraints are combined into the Full Income constraint which forces all sources of income minus all expenses to equal zero, as represented in Equation 7 (Huffman, 2010).

(7) $WT + V - Wt_1 - Wt_2 - P_1x_1 - P_2x_2 = 0$

5.4.4 Constraining Optimization

The above time and income constraint, coupled with the utility function, yields the following constrained optimization equation that utilizes a Lagrange multiplier, λ, in Equation 8 below.

(8) $U(G_1(x_1, t_1; \varphi_1), G_2(x_2, t_2; \varphi_2); \tau) + \lambda(WT + V - Wt_1 - Wt_2 - P_1x_1 - P_2x_2)$

Here, λ represents the marginal utility of income. When utility is maximized λ will equal zero.

5.4.5 First Order Conditions

To determine the first order conditions, the partial derivatives of the constrained maximization equation are taken with respect to the variables and set equal to zero (Eatwell, 1987; Huffman, 2010). The following first order conditions, seen in Equations 9 through 11, hold at the constrained maximum.

(9) $x_i\colon\ U_{Z_i} * G_{ix_i} - \lambda P_i = 0$

(10) $t_i\colon\ U_{Z_i} * G_{it_i} - \lambda W = 0$

(11) $\lambda\colon\ (WT + V - Wt_1 - Wt_2 - P_1x_1 - P_2x_2) = 0$

Comparing Equations 7 and 8, it can be seen that the wage rate, W, is equivalent to the price of time used to produce subsistence and market foods, otherwise known as the opportunity cost. This opportunity cost only applies when firefighters face a direct conflict between subsistence and firefighting.

5.4.6 Marginal Cost

From these first order conditions, the marginal cost, MC, of subsistence foods and market foods can be calculated. Equation 12 below calculates the marginal cost of subsistence and market foods (Huffman, 2010).

(12) $MC_{Z_i} = \frac{W}{G_{it_i}} = \frac{P_i}{G_{ix_i}} = \pi_i(W, P_i, \varphi_i)$

The above equation indicates that the marginal costs of subsistence and market food production are dependent upon the wage rate, W, the price of the purchased goods, P_i, and the technology factor, φ_i. One important result of this equation is that as the wage rate increases, as it does during the fire season when forest firefighting jobs are available, the cost of producing another unit of food, from either subsistence or market, goes up. These equalities must hold because the marginal cost is directly related to the wage rate – as wages increase the cost of doing anything besides earning wages increases – the price of goods – as the price of a good goes up, the cost of generating one additional unit increases – and technology – as technology improves the cost of producing an additional unit decreases.

5.4.7 Determining Demand

One of the goals of the model is to determine the demand for time spent on forest firefighting employment. To this end, the first order conditions and the time constraint are used to derive a general demand function for the amount of time spent on forest firefighting labor. Equation 13 specifies the demand for time spent producing subsistence and market foods, and Equation 14 uses that demand function, coupled with the time constraint to derive a general demand function for forest firefighting labor.

(13) $t_i = T + V - \frac{P_i x_i}{W} \quad i = 1,2 \quad t_i(P_i, W, V, \varphi_i, \tau)$

$$h = T - t_1 - t_2 = demand\ for\ h \quad h(P_i, W, V, \varphi_i, \tau) \tag{14}$$

Equation 11 states, for example, time spent producing subsistence or market foods is positively related to total time available and cash available to spend on subsistence, and negatively related to the marginal cost of production. Equation 12 indicates that the price of purchased inputs for subsistence and market foods, the wage rate, unearned income, technological efficiency, and tastes all factor in to the demand for hours worked on forest firefighting. Equation 12 indicates that the number of hours of firefighting demanded is positively related to the total number of hours available and negatively related to the amount of time required to produce subsistence foods and purchase market foods. The more time someone devotes to subsistence the less time they have available for firefighting.

5.4.8 Theoretical Model Results

Once the model has been created, the response of variables to changes in other variables can be evaluated. For example, the response of subsistence food production to increased forest firefighting wages can be predicted.

Evaluating Equation 12 in combination with Equation 10, it becomes evident that as W increases, representing additional forest firefighting income to be made, the marginal cost of producing goods increases. However, the marginal cost will increase more for the production of time intense goods, such as subsistence. It can also be determined that as W increases the demand for hours spent fighting fires will also increase. Increases in income from firefighting are predicted to be accompanied by a substitution of market foods for subsistence foods because market foods are less time intense in their production.

Contrariwise, if the wage rate decreases, which happens when the fire season ends, the marginal cost of producing foods, particularly subsistence food, declines. Accompanying this decline in firefighting wages, a substitution of subsistence foods for market foods would also be seen.

Due to the time intense nature of producing subsistence foods, compared to the relatively low time required to purchase market foods, the marginal cost of subsistence foods is more sensitive to changes in the wage rate. The magnitude of the substitutions is dependent on the marginal costs, as well as dependent on the cost of time and the other purchased inputs. For extremely high prices of market goods, it is possible that the cost of subsistence would still be more cost effective, even with increases in its marginal cost due to increasing forest firefighting wages.

The use of a household production model allows the development of demand functions with general equations and that yield meaningful results. It can accommodate, upon further development, specific elasticities of substitution of goods, the accounting of differences in quality of subsistence capital through φ_i, and community preferences for subsistence versus market foods through τ. The model can also allow the calculation of the cross-price elasticities for subsistence and market foods and can further the understanding of the complicated relationship between these goods that act both as complements and substitutes.

5.5 Food Production Simulation

5.5.1 Cobb-Douglas Production Function

In the food production simulation discussed below, a Cobb-Douglas utility function is used within the household production model to estimate the production of subsistence and market foods. This function will take the form of Equation 15.

(15) $Y = Al^{\alpha}c^{\beta}$

Where Y is the total production of goods created using l, labor, and c, capital. A is the measure of productivity. Measures of output elasticity are represented by α and β.

The Cobb-Douglas production function is a widely used, simply formed function that can be used to model utility or production (Eatwell, 1987). In the case of production, it can be used to represent the relationship between any two necessary inputs and the elasticity of those inputs (Eatwell, 1987). The Cobb-Douglas function, though simple, has been found to explain data well and is easy to manipulate to fit the needs of various economic systems. The function can expanded to accommodate several aggregated homogenous production functions and can be used with decreasing, constant, and increasing returns to scale (Eatwell, 1987).

The Cobb-Douglas production function works well for the production of both subsistence large land mammal production and market food production. Hunting large land mammals takes significant inputs of time and income, as discussed further and estimated below. Large land mammals, such as moose, cannot be produced without both of these inputs. Market produced meat, on the other hand, takes almost no time to produce, however, it does take *some* time. Market produced meat is generally more expensive, but the time it takes to produce is orders of magnitude less than subsistence produced large land mammals.

The exponents represent output elasticity and indicate how the overall output changes as the inputs change (Eatwell, 1987). For example, if hunting hours increased by 50% and α was equal to .6, then output would have increased by 1.2%. *A* reflects the overall productivity. One community, Community A, could be more productive than Community B, given the same inputs and elasticities. This increased efficiency of Community B can be captured by *A* (Eatwell, 1987). The Cobb-Douglas production function requires that shares of inputs are held stable over time.

5.5.2 Simulating the Becker-Type Model

Utilizing a Becker-type household model for simulating rural community food production is well suited, due to the high levels of sharing and group production that take place in rural Alaska (Baggio et al., 2016; Kofinas et al., 2016). Extensive subsistence food sharing networks in Rural Alaska communities mean that a fire crew's absence during the hunting season does not *necessarily* decrease the community's or an individual household's subsistence food production (Baggio et al., 2016; Kofinas et al., 2016). The communal nature of fish harvesting, the most frequently cited current subsistence/firefighting conflict, lends itself to easy labor substitution by other community members for the absent firefighters, thanks to harvesting regulations (Alaska Administrative Code, 2000).

The sharing of capital necessary to produce subsistence foods straddles the line between food and cash sharing. Capital is shared at a lesser rate than subsistence foods, but at a higher rate than cash (Kofinas et al., 2016). It is through the sharing of capital, such as four-wheelers, fuel, bullets and more, that firefighters share part of their income. This is similar to how household members in a traditional household would share mixing bowls or a refrigerator.

Cash sharing networks, however, are much scarcer and job opportunities are extremely limited, so a crew missing-out on a fire assignment decreases the community's income level (Baggio et al., 2016; Kofinas et al., 2016). What reduced cash is present in the economy is less likely to be shared than subsistence foods or capital, meaning that individual households will potentially suffer more greatly from the loss of a firefighter's income than from their subsistence production during the regular fire season (Baggio et al., 2016; Kofinas et al., 2016). However, since individual firefighter decisions can affect the entire crew, for example, having one crew member too few can stop the entire crew from being dispatched and earning income, firefighting decisions are still made thinking of the community as a household with shared resources and capital. Due to these community-considering behaviors, a traditional household model is appropriate to simulate food production and firefighting.

The food production simulation was carried out on *average* roaded and non-roaded rural Alaska communities. Data for roaded communities for which firefighting and subsistence data overlapped were averaged by data type. Examples of averaged data include population, percent of population between the ages 16 and 65, subsistence minimums and subsistence food production costs. The same averages were calculated for non-roaded communities for which firefighting and subsistence data overlapped. Other data from national sources such as time use and nutritional information were used for both roaded and non-roaded communities. Lastly, data that was collected from surveys and interviews was averaged and used for both roaded and non-roaded communities, due to the small sample size for roaded communities that would have rendered averages for roaded communities unreliable for the purposes of modeling.

Due to the nature of the research question, “how will climate altered boreal wildfire regimes impact subsistence food production,” the food production simulation focused on the production of large land mammal such as moose and caribou and market meat production. The additional firefighting opportunities are modeled to be in direct overlap with the fall subsistence hunting season.

Finally, in congruence with firefighter responses to survey and interview questions, it is assumed that all firefighting opportunities are accepted. This assumption is valid given that 94% firefighters interviewed, stated they would always accept fire assignments, regardless of potential overlap with the fall hunting season, and 87% of surveyed firefighters state that, even if the fire season was four weeks longer, they would always be able to put a crew together and respond to a dispatch.

5.5.3 Estimated Demographics and Subsistence Minimums

Population data from the 2016 Alaska Department of Labor was used to calculate an average population and percent of population between the ages of 16 and 65 for roaded and non-roaded communities. The average population for roaded communities was 1,655 with 60% of the population between the ages of 16 and 65. For non-roaded communities, the average population was 450 with 55% of the population between the ages of 16 and 65. These values were used to calculate the minimum amount in pounds of subsistence harvested large land mammals. These minimums represent the minimum amount of subsistence produced large land mammals necessary to adequately feed the community. Minimums were estimated by averaging the lowest per capita recorded large land mammal harvest across communities.

5.5.4 The Time Constraint

The time constraint (Equation 3) was estimated using detailed data from the American Time Use Survey, which were survey results regarding time spent hunting large land mammals and 2015 firefighting wage data.

Detailed data on time use was also collected from the 2016 American Time Use Survey. Specific categories of time use were added to determine the amount of time available for subsistence or firefighting in rural Alaska. While it stands to reason that Alaskans, and particularly rural Alaskans, spend their time differently than the average American – shorter commutes to work for example – the American Time Use Survey is the only comprehensive account of time use available. There is no time use data specific to Alaska or to people who engage in subsistence. According to the American Time Use Survey, individuals have 8.8 hours per day available for participating in subsistence or firefighting (US Department of Labor, 2016).

Data from firefighter surveys was used to estimate time spent per pound of subsistence large land mammal produced. (Survey methodology and results are discussed in Chapter 3.) The average time required to produce a usable pound of large land mammal protein was 1.9 hours.

The average length of dispatch was derived from 2015 data on total annual crew wages, $totwage$, and weighted average hourly wage per 18 person crew. Wage rates for firefighting were given by the Alaska Fire Service. An average of $18.70 per hour, per person for rural Alaska fire crews was calculated (Branson, 2016). Using the weighted average hourly crew wage, ahw, of $18.70 per person, the average length of dispatch, $avgh$, for rural crews was 800 total hours – approximately 47 hours per firefighter (Branson, 2016). See Equation 16.

$$(16) \quad avgh = \frac{totwage}{ahw}$$

This average length of dispatch was held constant in the food production simulation. Although it stands to reason that the length of dispatch may increase as the fire season lengthens, there is no available estimate for the increase in dispatch length; using the most recent data available on average dispatch length is the best possible estimate for the future.

It is assumed that the firefighting crew accepts all additional dispatches because of interviews and surveys conducted herein. Firefighters responding to interview and survey questions about their willingness to go on dispatches indicate that they would always be able to find a full crew's worth of firefighters to respond to a dispatch.

5.5.5 Income Constraint

Imposing an income constraint on food production ensures that the simulation does not use more money than a community has to produce foods when the system of equations is maximized. For this food simulation, the cost of producing market and subsistence foods, combined with other household costs, was constrained to be less than or equal to total community income plus additional firefighting wages. See Equation 17.

(17) $W(D * 800) + I - O(I) - P_s x_s - P_m x_m >= 0$

Where W equals the weighted average hour wage of \$18.70 for fighting fires, and D equals the total community dispatches. D is multiplied by the average of 800 hours per dispatch to get the total number of hours spent firefighting for the community. Dispatches are a function of the acres burned, as calculated in the negative binomial model for roaded and non-roaded communities, and the estimated increase in acres burned as generated by the GCMs.

I equals income, which is comprised of the average per capita income in 2015 dollars for roaded and non-roaded communities times average population, plus the additional income generated by the estimated increase in acres burned as estimated by the GCMs.

$O(I)$ equals other household costs as calculated from data collected by the McDowell Group (2009). Other household costs were, as previously stated, calculated from data collected by the McDowell group from rural communities and multiplied by the average number of households to arrive at total community value of other household costs. This data was originally collected in 2006 and was adjusted for inflation to 2015 dollars, in order to be consistent with firefighting wage data. Other household costs were then divided by total income to determine an average household cost as a percent of total income. Making other household costs a function of total income allows for additional firefighting income to be spent on items other than subsistence and market food production. Other household costs made up, on average, 97% of total income.

P_s equals the price of producing one pound of subsistence food, calculated by interview data to be \$1.11 per pound and x_s equals the number of community-wide pounds of subsistence harvested large land mammals. P_m equals the price of market produced meat, reported to be $4.24 per pound, and, lastly, x_m equals the number of market produced pounds of meat (Branson, 2016; Fall, 2014; McDowell, 2009). The amount of money required to produce one pound of subsistence harvested large land mammals was $1.11 per pound. Firefighters were asked what their cost for producing subsistence food was, *including* the cost of capital, such as bullets, fuel, and snow machines. The cost of producing subsistence foods calculated here was found to be similar to cost data from the McDowell Group that generated a cost of $0.68 per pound (McDowell, 2009). Replacement cost for subsistence harvest foods used was reported at between $4.00 and $8.00 (Fall, 2014; McDowell, 2009). Using these sources, the cost of subsistence foods assumed in the model was $1.11 and the cost of market meat was $4.24.

Average community income was calculated for roaded and non-roaded communities from the Alaska Department of Fish and Game, Division of Subsistence comprehensive subsistence surveys. The average income for roaded communities was $8.34 million, and the average income for non-roaded communities was $8.33 million (State of Alaska, 1980-2015).

5.5.6 Market Meat Constraints

In order to understand the maximum amount of substitutable meat that residents of a rural community could purchase from a local store, stores in four rural Alaska communities were contacted. Proprietors were asked the maximum amount of meat they could store. Those four indicated that they could sell more meat than they presently sell, however, they were unsure the absolute maximum they could sell if they were to regularly sell out. The average estimated maximum amount of meat proprietors reported they could sell and restock in a week was 250 pounds.

The constraint that market produced food could not exceed 250 pounds per week was imposed upon the market food production function for non-roaded communities. For roaded communities, this limit was used as well. Holding the market meat constraint at 250lbs for roaded rural communities keeps the time component of production the same throughout the simulation.

A minimum constraint was put on market produced meats as well. Firefighters interviewed shared that, despite a general preference for subsistence meats, market produced meats are still a regular part of most of the younger generations' weekly diets. This is validated by the McDowell cost data that indicates regular purchases of market produced meats comprise up to as much as 5% of a household's income (McDowell, 2009). Interviewees indicated that rural Alaska residents in the 65+ age range have a strong preference for subsistence foods and generally do not eat market produced meats. A very liberal minimum constraint was put on market food of one pound per week, or 52 pounds per year.

5.5.7 Subsistence Food Constraints

Subsistence food production was given a minimum constraint that required the simulation to produce at least a certain amount. This minimum was calculated by finding the lowest reported community level harvest of large land mammals between 1986 and 2015 for each community, factored into the averages for the simulation. This community minimum was then divided by the community population to calculate a per capita minimum subsistence harvest level. The minimum number of pounds per capita, $lbsPC$, for each community was then averaged and multiplied by the average community population, pop, to calculate the minimum number of pounds required by the average community for the food production simulation, $submin$. See Equation 18.

(18) $submin = lbsPC * pop$

The minimum per capita subsistence harvest level of large land mammals was then averaged for roaded and non-roaded communities and was 50.4lbs and 127.7lbs, respectively (State of Alaska, 1980-2015).

Subsistence food production was also given a maximum constraint. This constraint was necessary because the maximization of utility would otherwise result in continued production of either subsistence or market foods to increase overall utility, potentially finding solutions with unrealistic amounts of subsistence produced. Considering the extremely low reports of food security in rural Alaska, subsistence maximums were developed by tripling the average harvest levels for roaded and non-roaded communities (Kofinas et al., 2016; Magdanz et al., 2016).

For the simulated roaded community this maximum was 258lbs per person of large land mammal protein. For the simulated non-roaded community, this maximum was 513lbs per person of large land mammal protein. These maximums are still well below the one moose per hunter regulations that would generate 549,450lbs for roaded and 112,500 for non-roaded communities (State of Alaska, 2017).

5.5.8 Subsistence Food Production

Cobb-Douglas production functions were used for the production of subsistence and market foods. The production function for subsistence large land mammal production was estimated from interviewee reports of average time required to harvest large land mammals – in this case moose, interviewee reports on the annual household cost of subsistence, Alaska Department of Fish and Game reports on annual pounds of subsistence harvest, and scholarly research estimates on the number of usable pounds per moose (de la Montaña et al., 2015).

Labor and capital inputs were each given unit elasticity of output at .5 for α and β, assuming 0.5 output elasticity gives a 1 to 1 increase in output with each additional unit of input. For lack of any measure output elasticity regarding subsistence productivity inputs, a 1 to 1 ratio was the most mathematically simple assumption to make.

The coefficients for labor and cash inputs were calculated from the average subsistence harvest productivity reported by surveyed firefighters. With 1.9 hours reported per pound of usable protein, $1.11 per pound of subsistence harvested food, and unit elasticity of output assumed the subsistence large land mammal harvest productivity, A, was calculated to be 0.688 in order for output to equal 1 pound (de la Montaña et al., 2015). See Equation 19, which shows the original Cobb-Douglas equation and estimated equation.

(19) $$Y = Al^{\alpha}c^{\beta}$$

$$1lb\ usable\ protein = 0.688 * 1.9hrs^{.5} * \$1.11^{.5}$$

5.5.9 Market Food Production

Market food production was similarly estimated using a Cobb-Douglas production function. The cost per pound, as previously stated, was collected from Fall's (2014) paper on subsistence. When adjusted to 2015 dollars, this value was \$4.26 per pound. This was confirmed by McDowell cost data for rural Alaska (McDowell, 2009). Labor required to produce one pound of market meat was assumed to be 0.11 hours. This estimate was based on the American Time Use Survey for lack of time use data specific to rural Alaska (US Department of Labor, 2016).

Unlike subsistence food production, output elasticity was not assumed to be 0.5. Instead, α was assumed to be equal to zero and β was assumed to be equal to 1. This assumption was made to reflect that an additional unit of labor would not, in this situation, produce any more food – simply as spending more time at the grocery store does not generate more food (de la Montaña et al., 2015). Only additional inputs of capital will generate additional output of market food (de la Montaña et al., 2015). Using these estimates of labor, capital, α and β, A is estimated to be 0.235. See Equation 20.

(20) $$Y = Al^{\alpha}c^{\beta}$$

$$1lb\ market\ meat = 0.235 * 0.1hrs^{0} * \$4.26^{1}$$

5.5.10 Utility Maximization

Maximizing the utility gained from subsistence and market foods requires the application of a utility function, such as was given in Equation 3.

(3) $$Utility = U(Z_1, Z_2; \tau)$$

In this food production simulation, the taste parameter, τ, was informed using interviews of rural Alaska firefighters who stated they themselves, and particularly their community elders, preferred subsistence foods to market foods, but did not prefer subsistence foods exclusively (Please see Chapter 3 for survey methodology and results.). This partial preference for subsistence foods was given a value of .7 preference out of 1.0 (Eatwell, 1987). A value of .5 would indicate equivalent preferences between subsistence and market foods where a value of 1.0 would indicate a preference for only subsistence foods.

The value of .7 was chosen to represent a strong, but not overwhelming preference for subsistence foods. The utility function used in the simulation takes on a Cobb-Douglas shape which results in Equation 21

$$(21) \qquad MAX[U = subsistence^{\tau_1} market^{\tau_2}]$$

Where U equals utility, τ_1 equals the preference for subsistence foods, and τ_2 equals the preference for market foods.

The maximization of utility, based on subsistence and market foods, generates the demand that causes the simulation to produce subsistence and market foods.

Results

5.6 Simulation Results

5.6.1 Econometric Results, GCMS, and Utility Maximizing Food Production

The food production model is coupled with the coefficients from the econometric models explaining the impact of increased acres burned on community firefighting wages and crew dispatches. These utility maximizing food production simulations are subject to increasing numbers of acres burned estimated by the GCM models discuss earlier. Three levels of increasing acres burned from the GCMs were used which represent a 1%, 15%, and 47% increase in acres burned across critical, full, and modified lands.

5.6.2 Food Production Relative to Increasing Acres Burned

For roaded and non-roaded communities, at all levels of acres burned, market produced meats achieve the maximum amount allowed. For roaded communities, at a 1% and 15% increase in acres burned, there is enough time available for subsistence to satisfy subsistence minimums. With an increase between 1% and 15% in acres burned, subsistence harvest levels of large land mammals also rise, as there is additional income but still enough time available to engage in subsistence. Subsistence maximums are achieved at a 15% increase in acres burned.

For roaded communities, subsistence levels decrease between a 15% and 47% increase in acres burned. Subsistence minimums are met at the 15% increase for roaded communities. At the 15% increase in acres burned, production levels are below the subsistence maximum and the time constraint is binding. At the 47% level increase in acres burned, subsistence minimums are not met for roaded communities. The time constraint is binding but the income constraint is not.

For non-roaded communities, with lower populations and higher minimum subsistence requirements, the increase from 1% to 15% in acres burned decreases subsistence levels. Subsistence minimums are not met at the 15% or 47% level increases in acres burned. For both the 15% and 47% level increases in acres burned, the time constraint is the binding constraint that limits subsistence hunting production.

These results indicate that the increases in fire activity indicated by the GCMs are likely to result in decreased capability for communities to meet their minimum food requirements through fall subsistence hunting of large land mammals. These results indicate that, based on current productivity and per capita community subsistence minimums, in order to meet subsistence harvest needs communities will either need to refuse dispatch opportunities, shift subsistence harvest to other species, shift subsistence harvest to other times – such as the winter hunting season – or use increased income to invest in higher efficiency harvesting gear.

5.6.3 Comparison to an Individual Community's Data

Average community data used in the above food simulations were compared to actual data from Ruby, Alaska, a community engaged in Type 2 firefighting and subsistence. It is also a community that has several years of data. There are only two years, 1999 and 2010, for which the community has both non-zero firefighting wages and a comprehensive subsistence survey that includes harvest of large land mammals.

In 1999, the total harvest of large land mammals was 14,465 lbs, the firefighting wages totaled $33,841, and the crew was dispatched one time. When these wages and dispatches are put into the food simulation along with the general demographic data for Ruby, the estimated harvest of large land mammals is 14,441 lbs. This is a 1.2% difference compared to the actual harvest in Ruby.

In 2010, the total harvest of large land mammals was 15,194 lbs, the total firefighting wages totaled $134,999, and the crew was dispatched three times. When these wages and dispatches are put into the food simulation along with the general demographic data for Ruby, the estimated harvest of large land mammals is 15,180 lbs. This is a 0.1% difference compared to the actual harvest in Ruby.

These differences between the modeled food simulation and actual data are to be expected, as the model is based on community averages from several different geographic regions, with different levels of productivity, around the State. It is likely that productivity rates for large land mammals are higher/lower in Ruby than in the communities represented through firefighter surveys and interviews. While the model does not perfectly predict subsistence large land mammal harvest in Ruby, the error range indicated by this model can be improved upon with increased region or community specific data. As discussed in the below section, further iterations of the model and additional data will decrease error ranges and increase model accuracy.

Discussion

5.7 Justification for Theoretical Models

5.7.1 Rejected Theoretical Models

There are several other models that could have been used in place of the Becker-Type model. Other similar models include the joint production model, the perfect substitutes model, and an econometric model (Barnett, 1977; Huffman, 2010). The joint production of goods is explicitly forbidden in the Becker-type model used here. Using a joint production model could allow the accounting for positive utility derived from devoting time to subsistence, t_1 (Barnett, 1977; Huffman, 2010). The additional utility gained from $t_1$would increase Z_1, subsistence food production, to a level higher than that which would be obtained through the Becker-type model (Barnett, 1977; Huffman, 2010). While this observation could be used to explain higher than expected subsistence harvest, compared to the results of the Becker-type model, this additional level of complexity does not add sufficient insight to warrant the additional complexity the model would create at this stage of development. The lack of available data regarding the joint production of other services, such as cultural cohesion and identity, also precludes the ability to estimate a joint production model.

The perfect substitutes model, or Gronau-type model, requires that the goods being produced by the household be perfect substitutes (Barnett, 1977; Huffman, 2010). While this model may initially seem to be a good fit for the production of subsistence and market foods, it is not. A pound of market produced meat may be a perfect substitute for a pound of subsistence produced meat, but many other goods are more complementary than substitutionary, such as seasonings for a moose roast or soft drinks consumed alongside a subsistence produced meal. Community members' differences in preferences for these meats and their different caloric contents result in subsistence produced protein, and market produced proteins not being perfect substitutes (USDA, 2016).

5.8 Limitations and Future Possibilities

5.8.1 Model Limitations

The Becker-type model and Cobb-Douglas production function both require assumptions that limit the usefulness of the models and limit the interpretation of the results of the model. In several cases the limitations and assumptions of both the Becker-Type model and Cobb-Douglas production function are the same. Often, the assumptions required of the model or function are the cause of the limitations on the interpretation of the results. The simplicity of the functions are the cause of most limitations (Eatwell, 1987; Huffman, 2010).

The Becker-type model used here assumes that there are no fixed costs (Huffman, 2010). Fixed costs of subsistence are debatable. Minimum maintenance of snow machines and off-road vehicles, for example, are fixed cost; however, it is possible to postpone this cost until the time period subsequent to the one being modeled, in which case fixed costs would disappear. The model also assumes only two constraints, time and income (Huffman, 2010). This limitation is overcome in the simulation by placing additional constraints, such as subsistence and market food constraints, but this does not account for all constraints felt by firefighters when considering subsistence food production. The realities of cultural and social obligations are difficult to fully capture in an economic model; however, some cultural obligations, such as providing elders with subsistence foods, is represented in the taste preference for subsistence foods when maximizing utility. The minimum subsistence requirement also incorporates some historic minimum level of satisfaction of cultural and social obligations.

Political, structural, and regulatory constraints, such as fire crew rotation schedules and bag limits, go unaccounted for in the Becker-type model.

The Becker-Type model assumes no barriers to entry into the forest firefighting workforce. This assumption ignores fitness requirements of forest firefighters. Additionally, not all communities have fire crews, which results in firefighters needing to relocate to another community that *does* have a fire crew prior to engaging in firefighting (Moses, 2003). The costs associated with this relocation and other costs associated with entering forest firefighting employment are not accounted for in the model. It is assumed that the community being modeled has a local forest firefighting crew, that the financial barriers to entry are negligible, and that increased hours devoted to forest firefighting are met by individuals capable of meeting fitness requirements.

Within the Cobb-Douglas production function, it is assumed that subsistence foods and market foods have unit elasticity of substitution and that technology is constant over the time period (Eatwell, 1987). It is also assumed that changes in income, economic growth, and input supply are not large enough to change the elasticity of substitution during the time period being modeled. Thus, the unit elasticity of substitution is an acceptable limitation.

Another limitation of the Cobb-Douglas function is that it requires each input to be essential (Eatwell, 1987). In this system, the result of this assumption would be that total community food cannot be produced without both subsistence foods and market foods. This is not true; for thousands of years Native Alaskan's produced all of their community food through subsistence alone (Robards & Alessa, 2003; Sobelman, 1985). However, in the present day, it is highly uncommon for residents of Rural Alaska to meet their nutritional requirements through subsistence alone (Fall, 2014). Despite the fact that total community protein needs *can* be met through subsistence or market foods alone, the reality is that total community protein needs are currently produced through a combination of subsistence and market foods making the assumption that both inputs are necessary reasonable.

In the Becker-Type model, only one type of employment and two goods are required for utility maximization. This is a highly simplified view of utility maximization (Chapin et al., 2008; Kofinas et al., 2016). It is assumed that other options for increasing employment do not exist, which is a reasonable assumption, given that employment opportunities in Rural Alaska are few and do not change dramatically from year to year (Shanks, 2013). As the goal is to model the demand for firefighting employment and the impact of increased firefighting wages on subsistence, all other types of goods that add to utility were assumed to remain constant during the time period, and unaffected by the changes being modeled. While this is an unrealistic assumption, it is a necessary and common assumption, particularly in this stage of modeling (Eatwell, 1987).

These assumptions taken together limit the questions that can be answered with the model. It is highly likely that given a very high wage, the marginal cost of subsistence would be higher than the marginal cost of market foods. In this scenario, the model would predict the eventual decline of subsistence. Several issues arise in this case that make it unlikely that these results will occur as predicted. Employment is limited, and while increased income does increase the marginal cost of subsistence, the reality of Rural Alaska is that exceptionally high unemployment is common (Kofinas et al., 2016; Shanks, 2013). These results are also unlikely due to the cultural significance of traditional and customary subsistence practices and the social obligations of sharing subsistence foods amongst households in the community, which cannot be taken into account due to the joint production constraint.

The model is also unable to completely evaluate the effects of policy changes within itself. Policy changes would need to be evaluated outside of the model to determine the impact on forest firefighting wages. Once this is determined, the effect on demand for forest firefighting employment and subsistence food production can be determined within the model.

The model can, however, evaluate the impact of changes in the cost of subsistence and market foods and changes in tastes regarding these (Huffman, 2010). It can also evaluate the impact of changes in firefighting wages on the demand for forest firefighting employment and on the level of subsistence food production, which is the purpose of this iteration of the model (Huffman, 2010).

5.8.2 Further Research

Many questions remain unanswered by this theoretical model. Gathering data to create an econometric model based on the theoretical model introduced here will be a critical step in understanding the actual demand for forest firefighting employment. While the theoretical model tells us how people would behave if our assumptions hold, surveys and data show us how people did and likely will behave when faced with opportunities and constraints.

Additional interviews with Rural Alaska forest firefighters would help increase the reliability of assumptions made using interview information. Additional interviews would also increase sample size and aid in the creation of distribution functions for food production simulation variables. Estimating output elasticities for subsistence and market food production would require additional information on time and capital inputs required for subsistence food production, large land mammal or other. Gathering numerous interviews from firefighters that engage in subsistence hunting within a single community or geographic area would give depth to the data and help account for geographic differences in land productivity that affect the productivity of labor and capital.

One important lingering question and important step for further research is how the modeled relationships will change due to climate change. Understanding how the supply of forest firefighter hours (the number of total hours needed to manage statewide wildfires) will change in the future will be critical in estimating the amount of forest firefighting income that will be available to communities, and how community subsistence will change into the future. This current research estimates the effect of increased acres burned on dispatches, but we assume that fires will be controlled using the same methods and ratios of dispatches per acres. If fires become more difficult to fully suppress, Type 2 firefighters could see even greater increases in dispatches, as two crews may be dispatched where only one would currently do.

This research can also be expanded to Type 1 firefighting resources. Understanding how increased acres burned will impact the utilization of Type 1 resources would be incredibly useful for Fire Management Organizations, particularly for budgetary planning. Incorporating additional climatology data on fire danger into the econometric models can help Fire Management Organizations and Rural Alaska communities have a better idea of how the fire season will affect suppression costs, wages, and dispatches to better plan for how they will adapt to the season.

Conclusion

5.9 Food Production Simulation and Future Changes

5.9.1 Evaluation of Impacts

Simulating market and subsistence food production allows for evaluation of the impact of changes to firefighting dispatches and wages and various fire management and subsistence policies on subsistence food production. In this case, potential increases in acres burned, as forecasted by GCMs, indicate that rural Alaska residents will continue to be able to meet their subsistence harvest needs – and continue to engage in this culturally and socially vital activity – throughout at least the next 100 years. That is unless acres burned increases in line with the most extreme fire forecasts.

Further refinement of the simulation and the creation of a user-friendly interface will enable communities to test subsistence food production sensitivity to a wide variety of policy and regulation changes as well as changes to cash income and time available for participation in subsistence.

Chapter 6: Conclusion

6.1 Overall Impact of Changing Boreal Fire Regime

6.1.1 Mixed impact

The impact of increased boreal wildfires on Rural Alaska subsistence hunting is affected by numerous factors previously discussed. These factors include location of community, magnitude of increase in acres burned, and more.

Factors such as community location determine to what magnitude a community will be affected by changes to the boreal wildfire regime – rural communities receive fewer dispatches than urban communities and have higher per capita subsistence food requirements. Given these static differences between communities, even a consistent increase in acres burned would not result in consistent impacts across Alaska.

When these static factors are taken into account, the effect of increased boreal wildfire remains complicated. The same increase in boreal acres burned and lost hunting time, due to firefighters being dispatched away from the community, can result in net positive outcomes for rural roaded communities and net negative outcomes from rural non-roaded communities, due to their varying rates of reliance on subsistence hunted protein. The increased reliance on subsistence hunted protein by rural communities requires larger investments of time in order to produce enough food to meet community minimums. Therefore, similar increases in dispatches could result in net negatives for rural non-roaded community subsistence hunting levels while generating net positives for road connected communities' subsistence hunting levels.

6.1.2 Impact Due to Changing Factors

The magnitude of the increase in Alaskan acres burned determines the impact on the community and its subsistence harvest. Increasing boreal wildfires do not have a strictly positive or negative impact on a community's ability to produce large land mammal subsistence hunted foods.

Across all community types, small increases in acres burned increase firefighting wages but do not significantly increase firefighters' time away from the community during the hunting season. Therefore, these small increases in Alaskan acres burned do not negatively impact a community's ability to meet subsistence hunting needs. However, large increases in boreal acres burned, upwards of 15%, drastically increase overall community income, but restrict time available for hunting, so much so that subsistence hunting minimums cannot be met in most cases.

6.2 Further Research Needs

6.2.1 Subsistence Productivity

The measure of subsistence hunting productivity calculated in this research is extremely broad. However, this is the first measure of subsistence productivity ever calculated. Further research on subsistence resource productivity by species and region is needed. This knowledge will improve all future studies of Rural Alaska economics. It also has the potential to improve evaluation tools designed for rural Alaska, such as the food production simulation developed in Chapter 3, by making these tools more accurate and representative of the true cost of subsistence production.

6.2.2 Subsistence Needs

In this study, nutritional needs were calculated based on national nutritional recommendations and a 2014 study on the percent of these nutritional needs currently being met by subsistence (Fall, 2014). Quantities of subsistence harvested foods needed to meet nutritional needs may differ from amounts of market foods needed to meet nutritional needs (Coker, 2018). Research on the nutritional and performance differences between subsistence and market protein sources is currently underway, and additional research is needed on overall nutritional requirements, daily grams of protein, fats, carbohydrates, etc., based on subsistence harvested foods. This research will help increase the specificity and accuracy of the food production simulations.

6.2.3 Firefighting Data Improvements

Linking firefighter crew data back to the communities of residence for firefighters would improve modeling capabilities. Dispatches and wages are intricately linked, however, the mathematical relationships between the two datasets were not perfectly collinear due to some firefighters belonging to crews outside of their home communities. For the wage model estimated in this study, wages were assigned to the closest community that had a fire crew. This slight messiness in data bleeds into the interpretation of the results. It is possible that relationships between Alaskan acres burned, community location, or Lower 48 acres burned would have been more significant or had smaller standard deviations if wages and dispatches were available at the same level.

Resolving this issue does not necessarily require additional research, but additional work in data linkage and database manipulation. During the course of this research, the State of Alaska, Department of Natural Resources has made significant improvements in data availability and data quality. Further steps in this vein will vastly improve the ability to estimate models based on wages and dispatches and strengthen interpretations of the results.

6.2.4 Rural Alaska Economies and Climate Change

In this research, climate change is only accounted for through its impact on boreal wildfire regimes. However, climate change will affect rural Alaska in many other significant ways such as altered seasonal movements of subsistence species, changing and unpredictable travel conditions, and stronger storms (Brinkman et al., 2016). This research exists at the beginning of understanding the socio-economic impact of climate change on rural Alaska. Further research can incorporate the impact of changing boreal wildfire regimes with the impact of climate change on changing migration patterns. None of these facets of a changing climate exist in absence of the other, so it is important that future research continues to combine the various impacts of climate change to understand its total impact.

6.2.5 Policy Changes

Several policy changes were suggested in this research. These policy changes, such as the institution of community bag limits, bring problems and their solutions to the same social level. These policy changes empower actors at the local level to solve problems also occurring at the local level. Few of these types of policy changes have been enacted, even for short times, in Alaska. Only after several years of communities operating under these changed policies will communities, policy makers, and researchers be able to evaluate the effectiveness of these changes and fully understand if these policies in fact enable community members to effectively adapt to climate change (Ford, Pearce, Duerden, Furgal, & Smit, 2010).

6.3 Uses of this Research

6.3.1 Body of Knowledge

This research adds to the body of knowledge regarding changes in subsistence food production in light of climate change. This research adds to past research on the impact of climate change on community members' abilities to navigate the land including navigation for subsistence reasons, changing harvest patterns and cumulative adaptations to climate change (Brinkman et al., 2016; Gustine et al., 2014; Hansen et al., 2013). The overall impact of climate change on rural Alaska will be a combination of the results of adaptation to changes in the fire season, seasonal prey migration patterns, and prey adaptations to climate driven changes in habitat and more. This research adds a valuable piece of analysis to the overall understanding of the impact of climate change through the combined lens of socio-ecological systems and classical economics (Chapin et al., 2009; Eatwell, 1987).

6.3.2 Applications of the Research

Policy makers can use this research to more fully understand the impacts of their policies in light of a changing climate. State and federal level policies take a long time to change, and endanger local citizens' abilities to meet their needs while operating safely and within the law (Ristroph, 2016a, 2016b). Policies that do not allow for local adaptations will put increasing hardships on communities as they attempt to adapt to changing social-ecological systems (Chapin et al., 2010; Chapin et al., 2009; Ford et al., 2010).

This research has useful applications for communities navigating the direct impacts of climate change. Communities can use these findings to engage in vulnerability analysis and resilience thinking (Chapin et al., 2009). Communities can use this research to plan their collective response to increased firefighting opportunities and increased income.

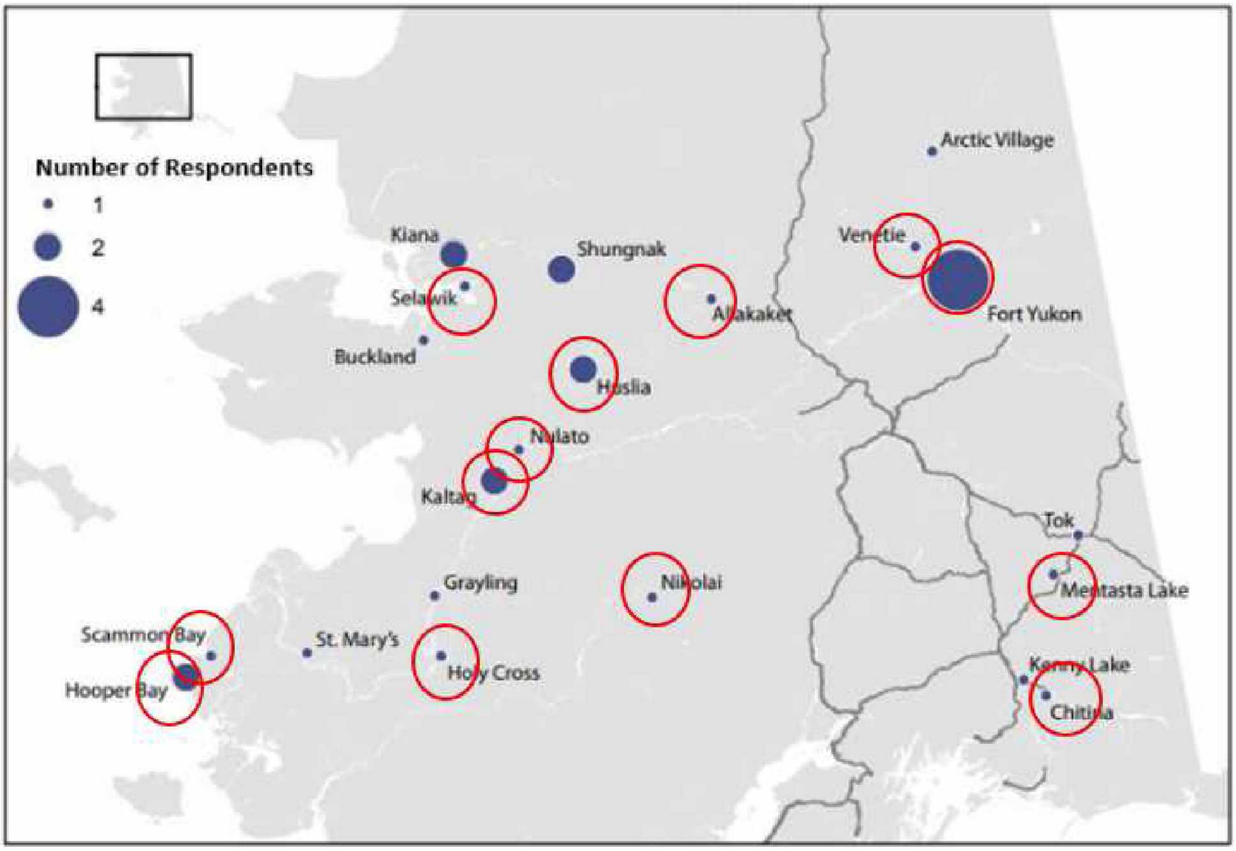
They can use the results to advocate for policy changes that will empower them to be able to adapt in ways that are most appropriate for their community needs and abilities.

Firefighters can also use this data to take action toward or advocate for policy changes that might empower them to have more community members qualify to be firefighters. They can also use the data to plan how they will individually respond to increased opportunities to fight fire. Perhaps they choose to coordinate with other community members to help each other meet subsistence hunting needs while still engaging in as many firefighting opportunities as possible. In other communities, some firefighters may use this research to plan to take only those opportunities that come early in the season so that they are available to hunt during the fall. Either way, firefighters, communities, and policy makers can use the results of this research to plan their adaptations to a changing climate.

Appendices

Appendix A:

Map 1. Respondent Communities



The map features number of respondents from each location surveyed. Red circles represent the communities of interviewees.

Appendix B:

Table 1. Interview Respondent Results

	Number of Respondents Who Mentioned Theme	Percent of Total Mentions of Categories by Respondents n=16	Mentions by Respondent's Region (%) Interior Non-Roaded: n = 11 Interior Roaded: n = 2 Coastal: n = 3	Mentions by Respondent's Firefighting Tenure (%) 0-14: n = 6 15-24: n = 7 25+: n=3	Mentions by Respondent's Primary Food Sharing Status (%) Provider: n = 2 Recipient: n = 4 Both: n = 8
Subsistence labor substitution: Someone else would/could hunt for me	14	88%	82% 100% 100%	100% 71% 100%	50% 100% 88%
Firefighting labor substitution: Someone else would/could go on a fire assignment for me	2	13%	18% 0% 0%	17% 14% 0%	0% 0% 25%
Cash similar sharing: I would buy someone else gas	7	44%	55% 50% 0%	50% 43% 33%	50% 50% 25%
Gear sharing: I would let someone else use my gear (4-wheeler, gun, bullets, fish wheel)	5	31%	36% 0% 33%	33% 14% 67%	0% 25% 50%
Subsistence-Fire complements: I would hunt around my fire schedule	11	69%	64% 100% 67%	83% 57% 67%	50% 75% 75%
Subsistence fire substitutes: I would purchase more food from the store	5	31%	36% 50% 0%	17% 43% 33%	50% 25% 25%
Subsistence level decline: If the fire and hunting seasons overlapped, the community's amount of subsistence foods would decrease	4	25%	27% 50% 0%	17% 29% 33%	0% 25% 25%
Subsistence labor Substitution: Someone else fishes or hunts for me (now if I'm on a fire)	10	63%	55% 50% 100%	67% 43% 100%	0% 100% 75%

Table 1. Interview Respondent Results (Cont.)

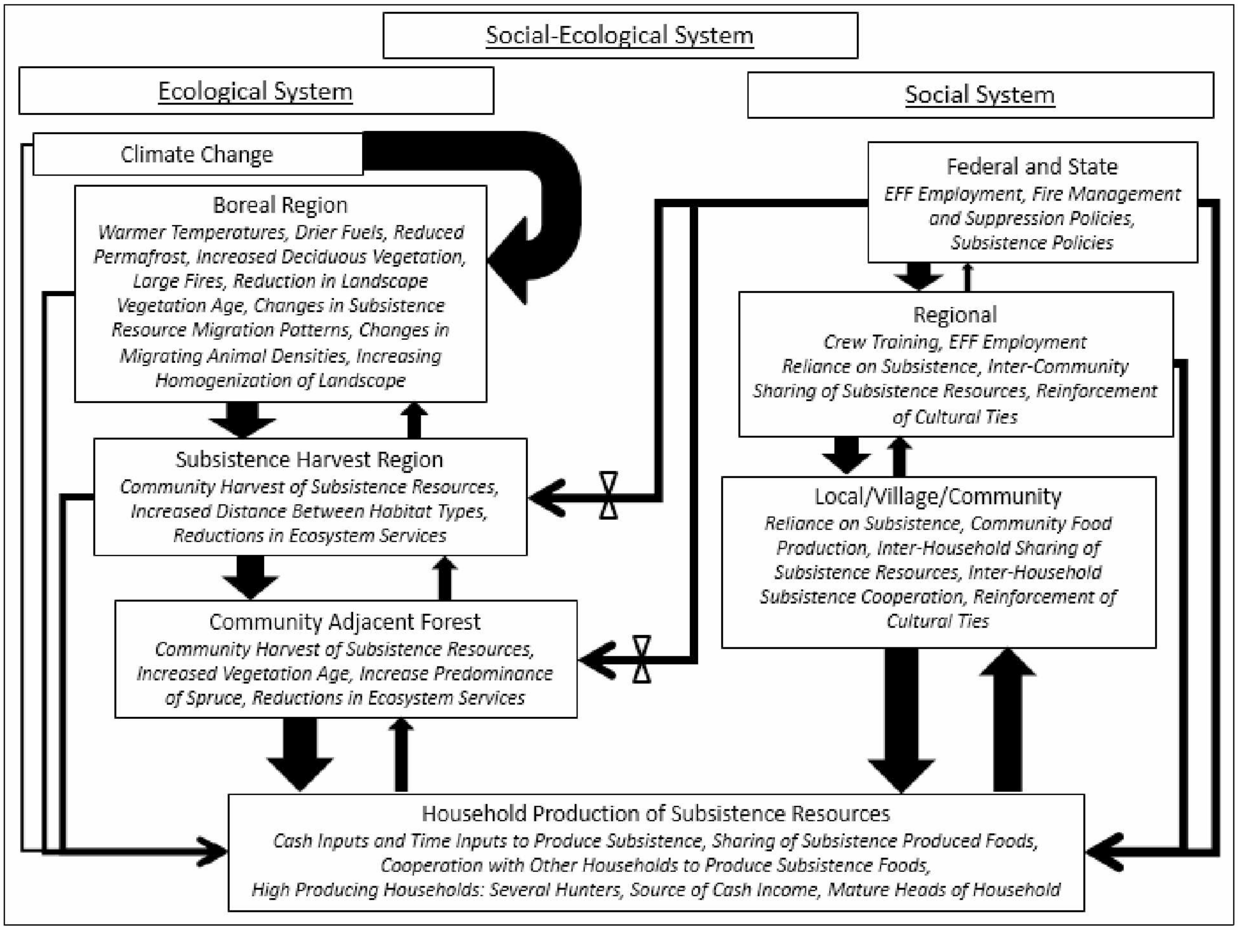
	Number of Respondents Who Mentioned Theme	Percent of Total Mentions of Categories by Respondents n=16	Mentions by Respondent's Region (%) Interior Non-Roaded: n = 11 Interior Roaded: n = 2 Coastal: n = 3	Mentions by Respondent's Firefighting Tenure (%) 0-14: n = 6 15-24: n = 7 25+: n=3	Mentions by Respondent's Primary Food Sharing Status (%) Provider: n = 2 Recipient: n = 4 Both: n = 8
Subsistence labor Substitution: I fish or hunt for someone else (explicitly stated)	5	31%	27% 0% 67%	50% 29% 0%	50% 0% 50%
general sharing of food mentioned	15	94%	91% 100% 100%	100% 86% 100%	50% 100% 100%
Subsistence-Firefighting Complements: I fish or hunt around my fire schedule	12	75%	82% 100% 33%	83% 71% 67%	50% 75% 75%
Gear Sharing (Take): I use someone else's gear	5	31%	36% 50% 0%	67% 14% 0%	50% 25% 38%
Gear Sharing (Give): Someone else uses my gear	2	13%	18% 0% 0%	0% 14% 33%	0% 25% 13%
Food Sharing (Take): I get subsistence food from others	13	81%	73% 100% 100%	83% 71% 100%	80%
Food Sharing (Give): I share subsistence foods with others	10	63%	73% 0% 67%	67% 57% 67%	77%
I would always accept fire assignments	15	94%	91% 100% 100%	100% 86% 100%	100% 100% 88%

Table 1. Interview Respondent Results (Cont.)

	Number of Respondents Who Mentioned Theme	Percent of Total Mentions of Categories by Respondents n=16	Mentions by Respondent's Region (%) Interior Non-Roaded: n = 11 Interior Roaded: n = 2 Coastal: n = 3	Mentions by Respondent's Firefighting Tenure (%) 0-14: n = 6 15-24: n = 7 25+: n=3	Mentions by Respondent's Primary Food Sharing Status (%) Provider: n = 2 Recipient: n = 4 Both: n = 8
I would cope with fire and hunting season overlap the way I cope with the fire fishing season overlap	10	63%	64% 50% 67%	67% 57% 67%	100% 100% 50%
I would/could cope with the fire-hunting season overlap in a new way	6	38%	45% 0% 33%	33% 43% 33%	50% 0% 50%
I already do winter hunting	1	6%	0% 50% 0%	0% 14% 0%	0% 0% 0%
I would shift my hunting to the winter moose hunting season	5	31%	27% 0% 67%	33% 29% 33%	50% 0% 50%
Started firefighting because it was the only job available	14	88%	91% 50% 100%	83% 86% 100%	50% 75% 100%
Family ties to firefighting	12	75%	73% 50% 100%	83% 57% 100%	0% 75% 100%
Started fighting fire due to educ. Requirements	2	13%	18% 0% 0%	17% 0% 33%	50% 0% 13%
Started firefighting because it admirable work	10	63%	64% 50% 67%	67% 57% 67%	0% 100% 63%

Appendix C:

Figure 1. The Social-Ecological System

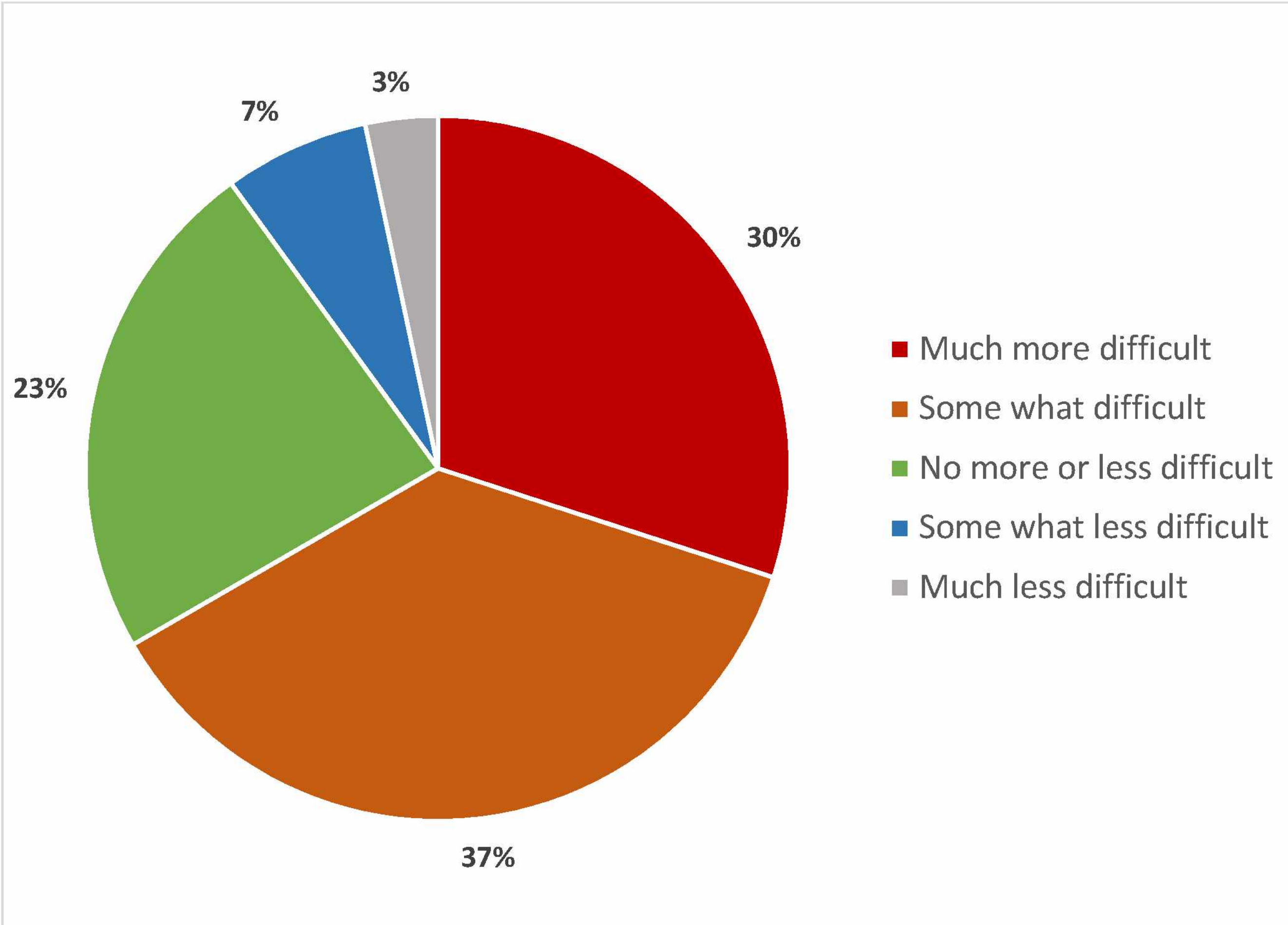


System diagram outlining Rural Mixed Subsistence-cash Social-Ecological System. The size and direction of arrows indicate the conceptual magnitude and direction of interacting processes and feedback between the different levels of the system. Bowties indicate pathways of current and potential future policy impacts. Spatial scale decreases and temporal rates of change increase from top to bottom.

Table 2: Summary of Survey Results

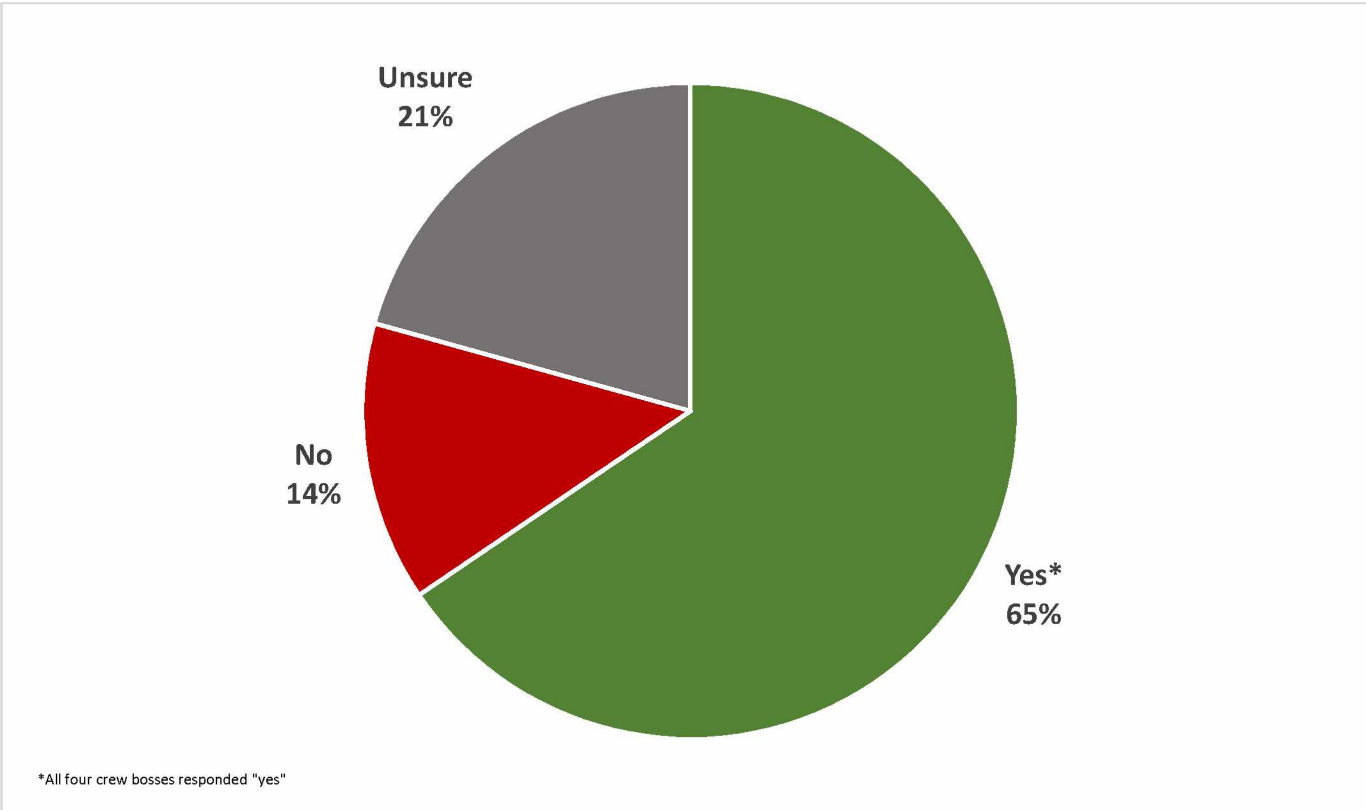
Selection of Survey Questions	Average	Min	Max	Mode
How many total years have you worked as a firefighter and/or crew boss?	17	3	38	3
How many fire assignments do you typically go on each year?	4	1	11	4
When do you typically stop fighting fire for the year?	August	June	December	August
How much would you need to earn for an extra TWO weeks of firefighting during the hunting season to make it worthwhile to you?	$3,250.00	$2,000.00	$ 4,000.00	$ 4,000.00
How much money did you spend on subsistence last year? (including gear and fuel for yourself or others)*	$1,730.00	$ -	$ 4,000.00	$ 500.00
In a typical year, how many days do you spend moose hunting?	16	3	37	14
On a typical moose hunting trip, how many people hunt with you?	3	1	7	3
In your hunting party, how many moose are typically harvested per trip?	2	1	4	2
Average hunter-days per moose	32	7	120	28
How many people live in your household?	4	1	10	3
How much did you earn last year as a firefighter or crew boss?	$9,715.00	$0	$38,000.00	$20,000.00
Approximately what percent of your household income comes from firefighting?	N/A	0-25%	76-100%	26-50%
**Amounts given were typical for 67% of respondents*				

Figure 2. Difficulty of Meeting Subsistence Needs



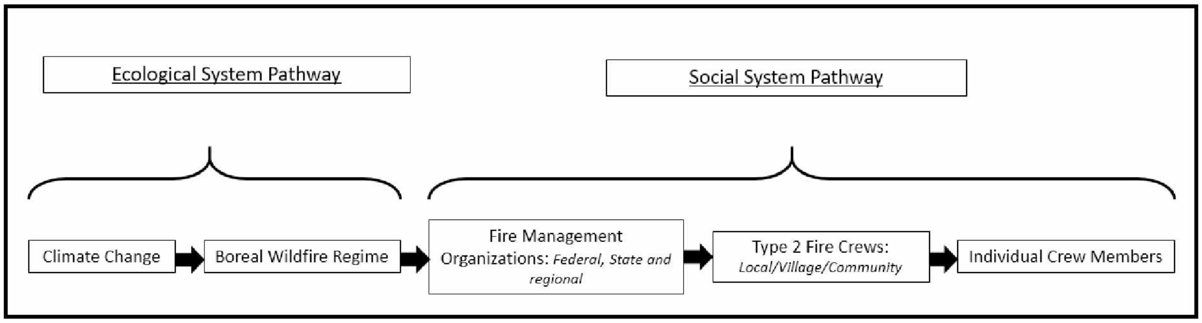
Survey Responses to “If the fire season lasted FOUR weeks longer than the typical end of the season, how difficult would it be to meet your subsistence needs?” Surveyed Firefighter anticipate that a longer fire season would increase the difficulty of meeting their subsistence needs.

Figure 3. Forgoing Hunting



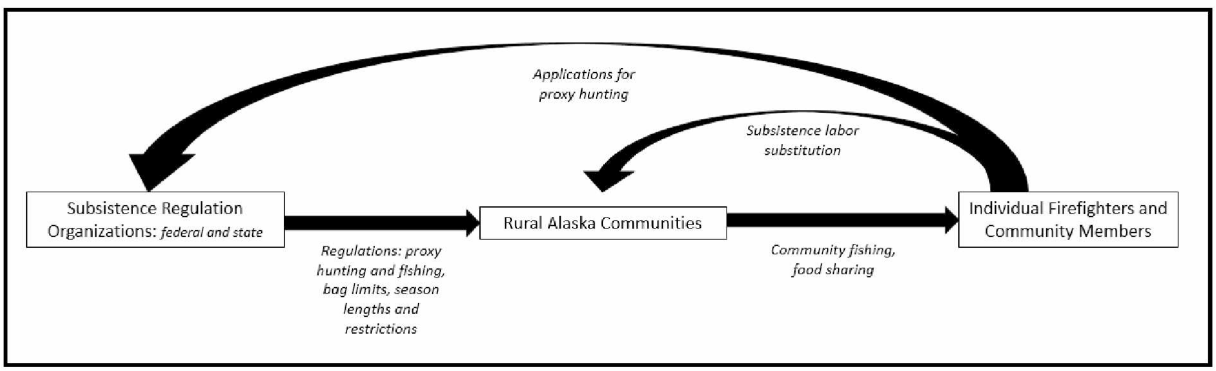
Survey responses to: “At any point, would you forgo hunting in order to continue fighting fire?” Firefighters surveyed indicated that nearly two thirds would forgo hunting in favor of fighting fire.

Figure 4. The Ecological to Social Pathway



One way that the social system is impacted by the ecological system is through firefighting shown here. Firefighting impacts cash income earning potential which is necessary for participation in subsistence.

Figure 5. The Subsistence Policy Pathway



State and federal agencies can promulgate regulation changes that increase the adaptive capacity of communities facing conflicts between firefighting and subsistence. Communities also have tools that they can utilize such as proxy hunting and subsistence labor substitution that they can use to increase their adaptive capacity without policy changes.

Appendix D

Table 3

Summary Statistics		
Average Annual Community Wage		
Urban	$ 1,089,572	
Rural Roaded	$ 135,619	
Rural Non-Roaded	$ 119,877	
Average Annual Crew Dispatch		
	Alaska	Outside
Urban	3.5	0.4
Rural Roaded	1.6	0.3
Rural Non-Roaded	1.3	0.4
Average Annual Acres Burned		
Critical Lands	1,189	
Full Lands	16,739	
Modified Lands	28,631	
Lower 48	5,838,856	
Western US	5,135,085	

Figure 6

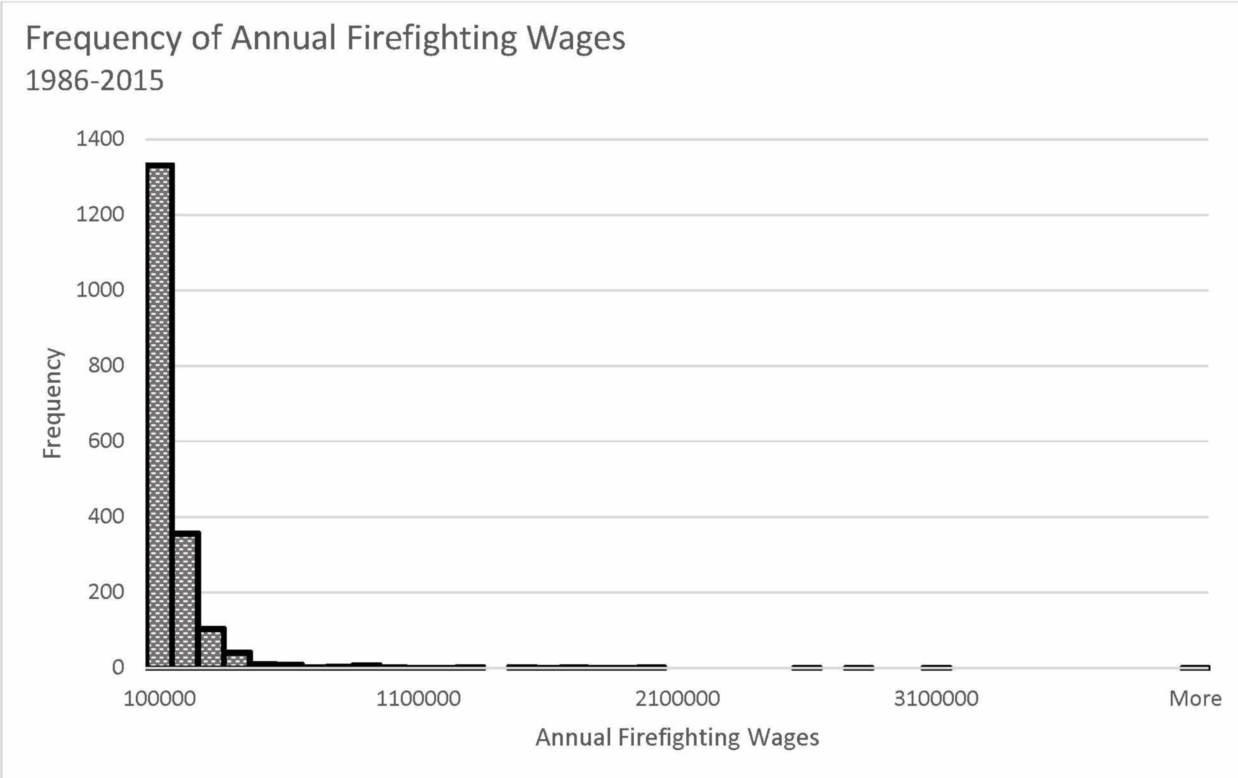


Table 3

Summary Statistics for Wage Model

Variable	Coefficient	P-stat	95% Confidence Interval	
ln(L48)	1.82	0.000	0.962	2.680
ln(Akacres)	0.14	0.032	0.115	0.258
u	1.67	0.143	-0.566	3.910
r	5.15	0.000	2.706	7.611

Appendix E

Figure 7

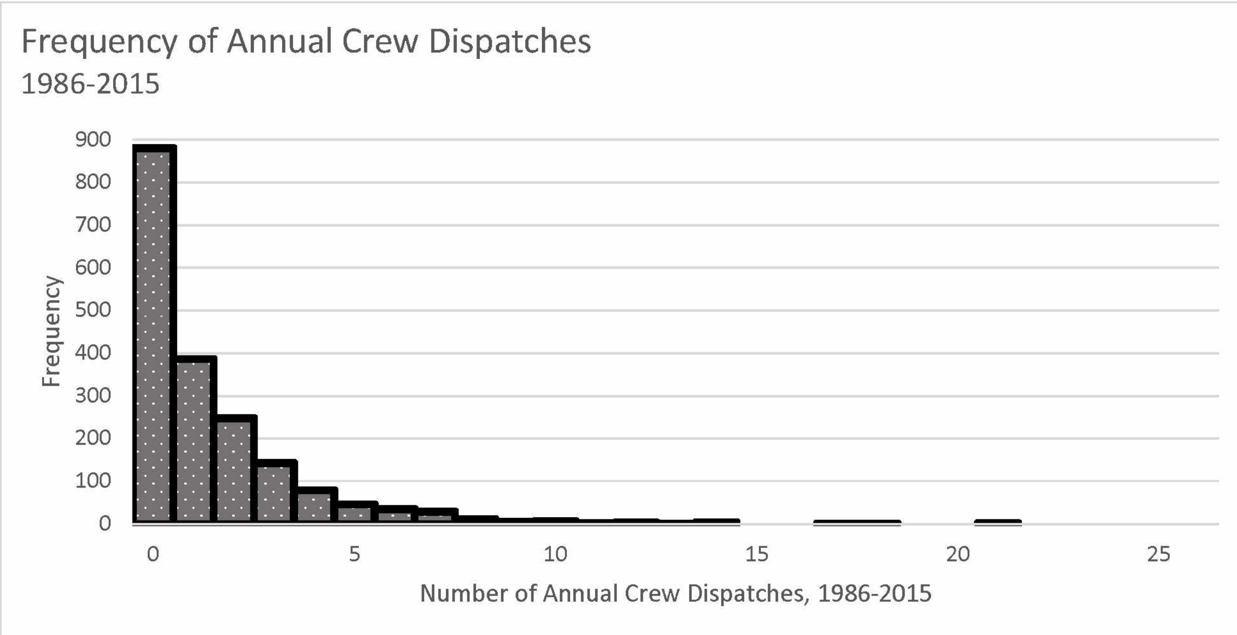


Table 5

Summary Statistics for Dispatch Model

Negative Binomial Model

Variable	IRR	P-stat	95% Confidence Interval	
ln(L48)	0.97	0.051	0.878	1.067
ln(Akacres)	1.03	0.000	1.014	1.045
u	1.72	0.013	1.122	2.645
r	1.28	0.002	1.098	1.044

Zero Inflated Model

Variable	IRR	P-stat	95% Confidence Interval	
ln(L48)	-0.72	0.061	-0.349	0.206
ln(Akacres)	-0.03	0.172	-0.667	0.119
u	1.51	0.000	0.674	2.353
r	0.81	0.057	-0.025	1.635

Appendix F:

UAF Institutional Review Board Exemption

UAF University of Alaska Fairbanks

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Institutional Review Board

909 N Koyukuk Dr. Suite 212, P.O. Box 757270, Fairbanks, Alaska 99775-7270

May 11, 2017

To:	Joseph Little, PhD Principal Investigator
From:	University of Alaska Fairbanks IRB
Re:	[900937-1] Up in Smoke: Exploring the Changing Relationship between Forest Firefighting, Subsistence and Climate Change

Thank you for submitting the New Project referenced below. The submission was handled by Exempt Review. The Office of Research Integrity has determined that the proposed research qualifies for exemption from the requirements of 45 CFR 46. This exemption does not waive the researchers' responsibility to adhere to basic ethical principles for the responsible conduct of research and discipline specific professional standards.

Title:	Up in Smoke: Exploring the Changing Relationship between Forest Firefighting, Subsistence and Climate Change
Received:	May 3, 2017
Exemption Category:	2
Effective Date:	May 11, 2017

This action is included on the June 7, 2017 IRB Agenda.

Prior to making substantive changes to the scope of research, research tools, or personnel involved on the project, please contact the Office of Research Integrity to determine whether or not additional review is required. Additional review is not required for small editorial changes to improve the clarity or readability of the research tools or other documents.

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